ORBITAL TRANSFER VEHICLE

CONCEPT DEFINITION AND SYSTEMS ANALYSIS STUDY

(NASA-CR-183683) ORBITAL TRANSFER VEHICLE: CONCEPT DEFINITION AND SYSTEMS ANALYSIS STUDY. VOLUME 2, BOOK 1: MISSION ANALYSIS AND SYSTEM REQUIREMENTS, PHASE 1 Final Report (Boeing Aerospace Co.) 155 p

N89-71395

Unclas

00/16 0219861

FINAL REPORT – PHASE I
VOLUME II, BOOK 1

MISSION ANALYSIS AND SYSTEM REQUIREMENTS
1986

NASA/MSFC
NAS8-36107

BOEING
D180-29108-2-1

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CONCEPT DEFINITION

AND

SYSTEM ANALYSIS STUDY

Final Report

Volume II Book 1

MISSION ANALYSIS AND SYSTEM REQUIREMENTS

D180-29108-2-1

December 1986

DPD NUMBER-637

DR NUMBER-4

CONTRACT NAS8-36107

Submitted to

The National Aeronautics and Space Administration

George C. Marshall Space Flight Center

By

Boeing Aerospace Company

Seattle, Washington 98124

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FOREWORD

This final report of the Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Study was prepared by Boeing Aerospace Company for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-36107. The study was conducted under the direction of the NASA OTV Study Manager, Mr. Donald Saxton and during the period from August 1984 to September 1986.

This final report is organized into the following nine documents:

VOL.	I	Executive Summary (Rev. A)		
VOL.	II	OTV Concept Definition & Evaluation		
		Book 1	-	Mission Analysis & System Requirements
		Book 2	-	Selected OTV Concept Definition - Phase I
		Book 3	-	Configuration and Subsystem Trade Studies
		Book 4	-	Operations and Propellant Logistics
VOL.	III	System & Program Trades		
VOL.	IV	Space Station Accommodations		
VOL.	V	WBS & Dictionary		
VOL.	VI	Cost Estimates		
VOL.	VII	Integrated Technology Development Plan		
VOL.	VIII	Environmental Analysis		
VOL.	IX	Implications of Alternate Mission Models and Launch Vehicles		

The following personnel were key contributors during the conduct of the study in the disciplines shown:

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ACRONYMS AND ABBREVIATIONS

ACC	Aft Cargo Carrier
AFE	Aeroassist Flight Experiment
AGE	Aerospace Ground Equipment
AL	Aluminum
ASE	Airborne Support Equipment
A/T	Acceptance Test, Auxiliary Tank
AUX	Auxiliary
AVG	Average
B/B	Ballute Brake
B/W	Backwall
CDR	Critical Design Review
CPU	Central Processing Unit
CUM	Cumulative
DAK	Double Aluminized Kapton
DDT&E	Design, Development, Test & Evaluation
DELIV	Delivery
DMU	Data Management Unit
DoD	Department of Defense
EPS	Electrical Power System
FACIL	Facility
FFC	First Flight Certification
FLTS	Flights
FOSR	Flexible Optical Surface Reflector
FRCI	Fiber Refractory Composite Insulation
F.S.	Fail Safe
FSI	Flexible Surface Insulation
FTA	Facilities Test Article
GB	Ground Based
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GRD	Ground
IOC	Initial Operational Capability
IRU	Inertial Reference Unit
IUS	Inertial Upper Stage

JSC	Johnson Space Center
L/B	Lifting Brake
LCC	Life Cycle Cost
L/D	Lift to Drag
MGSS	Mobile GEO Service Station
MLI	Multilayer Insulation
MPS	Main Propulsion System
MPTA	Main Propulsion Test Article
MSFC	Marshall Space Flight Center
OMV	Orbital Maneuvering Vehicle
OPS	Operations
OTV	Orbital Transfer Vehicle
PAM	Payload Assist Module, Propulsion Avionics Module
PDR	Preliminary Design Review
PFC	Preliminary Flight Certification
P/L	Payload
PROD	Production
PROP	Propellant
RCS	Reaction Control System
REF	Reference
RGB	Reusable Ground Based
R&R	Remove & Replace
RSB	Reusable Space Based
RSI	Reusable Surface Insulation
SB	Space Based
S/C	Spacecraft
SCB	Shuttle Cargo Bay
SIL	Systems Integration Laboratory
STA	Structural Test Article
STG	Stage
STS	Space Transportation System
T/D	Turndown
TDRS	Tracking Data Relay Satellite
TPS	Thermal Protection System
TT&C	Telemetry, Tracking and Control
WBS	Work Breakdown Structure

1.0 INTRODUCTION

This section provides a description of the study in terms of background, objectives, issues, organization of study and report, and the content of this specific volume.

Use of trade names, names of manufacturers, or recommendations in this report does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

And finally, it should be recognized that this study was conducted prior to the STS safety review that resulted in an STS position of "no Centaur in Shuttle" and subsequently an indication of no plans to accommodate a cryo OTV or OTV propellant dump/vent. The implications of this decision are briefly addressed in section 2.2 of the Volume I and also in Volume IX reporting the Phase II effort which had the OTV launched by an unmanned cargo launch vehicle. A full assessment of a safety compatible cryo OTV launched by the Shuttle will require analysis in a future study.

1.1 BACKGROUND

Access to GEO and earth escape capability is currently achieved through the use of partially reusable and expendable launch systems and expendable upper stages. Projected mission requirements beyond the mid-1990's indicate durations and payload characteristics in terms of mass and nature (manned missions) that will exceed the capabilities of the existing upper stage fleet. Equally important as the physical shortfalls is the relatively high cost to the payload. Based on STS launch and existing upper stages, the cost of delivering payloads to GEO range from $12,000 to $24,000 per pound.

A significant step in overcoming the above factors would be the development of a new highly efficient upper stage. Numerous studies (ref. 1, 2, 3, 4) have been conducted during the past decade concerning the definition of such a stage and its program. The scope of these investigations have included a wide variety of system-level issues dealing with reusability, the type of propulsion to be used, benefits of aeroassist, ground- and space-basing, and impact of the launch system.

1.2 OBJECTIVES AND ISSUES

The overall objective of this study was to re-examine many of these same issues but within the framework of the most recent projections in technology readiness, realization that a space station is a firm national commitment, and a refinement in mission projections out to 2010.

During the nineteen-month technical effort the specific issues addressed were:

a. What are the driving missions?

b. What are the preferred space-based OTV characteristics in terms of propulsion, aeroassist, staging, and operability features?

c. What are the preferred ground-based OTV characteristics in terms of delivery mode, aeroassist, and ability to satisfy the most demanding missions?

d. How extensive are the orbital support systems in terms of propellant logistics and space station accommodations?

e. Where should the OTV be based?

f. How cost effective is a reusable OTV program?

g. What are the implications of using advanced launch vehicles?

1.3 STUDY AND REPORT ORGANIZATION

Accomplishment of the objectives and investigation of the issues was done considering two basic combinations of mission models and launch systems. Phase I concerned itself with a mission model having 145 OTV flights during the 1995-2010 timeframe (Revision 8 OTV mission model) and relied solely on the Space Shuttle for launching. Phase 2 considered a more ambitious model (Rev. 9) having 442 flights during the same time frame as well as use of a large unmanned cargo launch vehicle and an advanced Space Shuttle (STS II).

The study is reported in nine separate volumes. Volume I presents an overview of the results and findings for the entire study. Volume II through VIII contains material associated only with the Phase I activity. Volume IX presents material unique to the Phase II activity. Phase I involved five quarters of the technical effort and one quarter was associated with the Phase II analyses.

1.4 DOCUMENT CONTENT

This document reports the work associated with the mission analysis effort and specification of the resulting system requirements. The mission analysis section describes each of the major mission categories (communication satellites, GEO satellite servicing, lunar program, planetary, and DoD) in terms of specific payload requirements, operational modes, and design reference mission profiles. The system requirements section provides further information on the mission profiles and defines the resulting system design requirements.

2.0 MISSION ANALYSIS

This section describes the results of our mission analysis task. The task can be divided into three parts: (1) mission set selection, (2) mission set definition, and (3) design reference missions. Mission set selection involves identification of mission categories and selection of OTV class payload types. Mission set definition involves characterization and scheduling of each payload category. The output of this subtask was reviewed by NASA and incorporated into a revised (Rev. 8) mission model from which design reference missions were derived.

2.1 MISSION SET SELECTION

The objective of this task was to review all payload types and select those which could be captured by an OTV system for further definition as described in section 2.2. The analysis was based on the NASA Rev. 7 mission model, which in summarized in table 2.1-1. This model was used to identify major mission requirements, which were used as the basis for the Boeing analysis. The following mission categories were identified:

a. Communications.
b. Scientific payloads.
c. DOD.
d. Satellite servicing.
e. Lunar.
f. Planetary.

These mission categories cover most high energy mission objectives. However, some of these objectives can be met without dedicated OTV flights (e.g., scientific payloads), or very few (e.g., unmanned servicing). The motivation behind the OTV mission analysis task was to develop a model that could most effectively and logically meet the mission objectives that fall under these categories. The design of specific missions is not important as long as the overall mission objectives are met, and the mission approach has a good probability of being adopted. This means, for example, that the GEO servicing missions given in the NASA Rev. 7 model could be reformatted in order to reduce GEO delivery requirements and reduce mission/program costs.

2.2 MISSION SET DEFINITION

This task is of fundamental importance to the study as the missions selected formed the basis for the derivation of OTV design requirements and the mission models are the

2472–84

TABLE 2.1-1

OTV MISSION MODEL COMPOSITION SUMMARY

1993 – 2010, REV. 7 (SS), 7–31–84

PAYLOAD NO. SERIES	MISSION GROUP	WEIGHT (LB) UP/DOWN	LENGHT (FT)	MISSION MODEL		IOC
				LOW	NOM	
13000	EXPERIMENTAL GEO PLATFORM	12000/0	30	1	1	1998/1994
13000	OPERATIONAL GEO PLATFORM	20000/0	35	11	18	2000/1996
13000	UNMANNED GEO PLAT. SERVICING	7000/4500	9	8	16	2000/1995
15000	MANNED GEO SORTIE	6500/6500 OR 14000/14000	15 OR 23	8	9	2003/1997
15000	GEO STATION ELEMENTS	13000–20000/0	15 – 20	2	3	2001/2002
15000	UNMANNED GEO STA. LOGISTICS	10000/2700	15	19	0	2000/ –
15000	MANNED GEO STA. LOGISTICS	16500/9000	27.5	0	34	2012/2002
17000	PLANETARY	2000–31000/0	< 25	12	21	1998/1993
17000	UNMANNED LUNAR	5000–20000/0	20	3	3	2001/2001
17000	MANNED LUNAR SORTIE	80,000/15,000	50	3	3	2007/2006
17000	LUNAR BASE ELEMENTS	80,000/0	53	3	3	2009/2008
17000	LUNAR BASE SORTIE/LOGISTICS	80,000/10,000	60	2	6	2010/2009
18000	MULTIPLE GEO PAYLOAD DELIVERY	9000–15300/2000–2600	22–42	31	51	1993/1993
18000	LARGE GEO SATELLITE DELIVERY	10000–20000/0	20–35	27	35	1998/1994
18000	UNMANNED GEO SAT. SERVICING	7000/4500	9	0	86	2002/1999
19000	DOD			137	137	1993/1993
			SUBTOTALS	267	426	
10100	REFLIGHTS			16	26	1994/1994
			TOTALS	283	452	

economic yardsticks for concept selection. The objectives of this task were to select a credible mission set by identifying user needs and defining mission characteristics that could meet mission objectives in a credible cost-effective way. The resulting mission model architecture reflected a logical path of development, including evolutionary growth of present programs, timely introduction of new programs, and adherence to economic and physical constraints. At all times attempts were made to retain interrelationships between similar or related missions (e.g., manned GEO and lunar).

Manned missions in particular received special emphasis because of their strong influence on the OTV design. The manned missions (GEO servicing and lunar sortie) were scrutinized to ensure that they were based on credible requirements and that their execution was cost-effective. This resulted in redefinition of both the GEO servicing and lunar missions. In addition to reducing OTV performance requirements, the revised versions of the two manned missions had much common hardware requirements, implying lower development costs and risk, thus increasing the credibility of both programs.

The manned mission analysis also led to a reassessment of satellite servicing philosophy. The analysis established a clear link between manned and unmanned servicing. This analysis is given in section 2.2.2.

The mission set definition analysis, described in this section, was input to NASA and incorporated, in part, into the Rev. 8 model described in section 2.3. NASA assessed and compiled the inputs of all three OTV study contractors into the new mission model and therefore, some of the mission descriptions given in this section do not correspond to the NASA OTV Mission Model, Rev. 8 missions.

2.2.1 Communications Satellites

Introduction

The communications satellite market was analyzed to help determine OTV flight rates through the year 2010. A variety of existing mission models were reviewed, principally Boeing, NASA, and Battelle models. These models included both transponder projections and specific flight manifests, though there was only loose correlation between the two. The mission analysis described below used these models as a starting point and built an OTV flight model which clearly defined the interrelationship between transponder demand, orbital crowding, satellite size, and OTV payload capacity. A plot of the different models examined is given in figure 2.2.1-1.

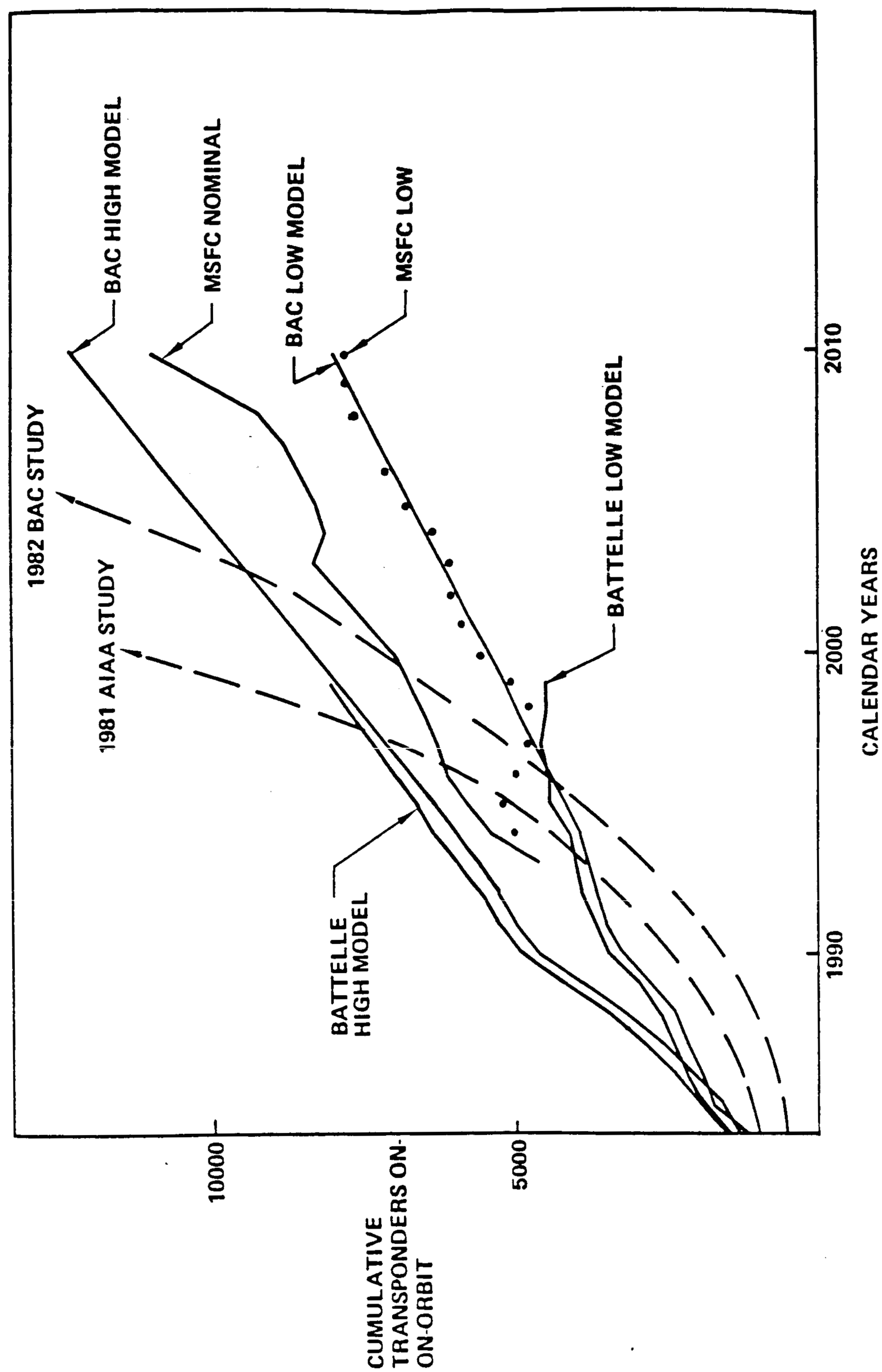

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Figure 2.2.1-1 Total World Transponders

The principal analytical tool was a spreadsheet program on a microcomputer. This allowed specification of relationships between all critical parameters and tracking of all changes made to individual parameters.

The key model driver was projected transponder demand. All other parameters were keyed to this growth curve. Transponder population goals were entered into the spreadsheet for each year through the year 2010. These transponder numbers were based on the Battelle high and low models. The number of transponders actually launched in a given year is a function of the number of transponders already operational, the number of transponders that have reached their operational lifetime, and spacecraft transponder design constraints (i.e., number of transponders per bus).

The second most important parameter was GEO arc capacity. This determines the numbers, and therefore also the sizes, of spacecraft that can be launched. Too many small capacity satellites can quickly saturate the available orbital slots. Spacecraft size is important because the OTV may be limited to multiple manifesting of not more than four satellites per flight, as the Shuttle Orbiter is. Most communications satellites are substantially smaller than the OTV payload capacity, so multiple manifesting becomes more efficient with larger satellites.

The OTV flight rate projections are dependent on the number of satellite deployments that can be captured by the OTV system. The model presented here assumes that OTV will capture all platform launches and all individual satellites that can be efficiently multiple manifested. This last assumption means that the four satellite payloads and their dispenser must weigh a significant portion of the OTV payload capacity.

Some assumptions related to OTV size must be made to determine OTV flight rates. This is a mission capture function and does affect the mission model analysis conclusions. However, these sizing assumptions were reached through an iterative process and appear to be realistic.

Transponder Growth Projections

Transponder growth characteristics have a strong effect on satellite launch rates and satellite bus size mix. Growth curves for both high and low models were taken from the Battelle study. These curves were extrapolated for the 2000-2010 timeframe.

In a given year, new transponder capacity must be added, transponder failures must be replaced, and transponders scheduled for deployment the previous year must be deployed. These relationships were incorporated into the spreadsheet model and yearly transponder launch goals were calculated.

The next step in the analysis was calculation of actual transponder deployments. This is a function of the types of satellites that physically carry the transponders. The study assumed three sizes for individual communications satellites (24, 48, and 96 transponders) and two sizes for platforms (192 and 384 transponders). The distribution of transponders between bus types is a function of orbital slot capacity and is discussed below. Transponders cannot be launched in groups smaller than the smallest bus size (usually 24 transponders). Transponders that cannot be launched in a given year are carried forward and launched the next year. This logic was incorporated in the spreadsheet model.

GEO Arc Capacity Limitations

The section of the spreadsheet that determines the satellite bus size mix uses inputs from the transponder deployment analysis. Transponder capture factors are arbitrarily assigned to each bus type. The number of satellite launches is then calculated for each type, starting with platforms and working down to small satellites, which capture all remaining transponders in 24 transponder increments. The number of satellites to be launched is then counted and added to the number of operational satellites (satellites at end of life are subtracted).

The spreadsheet shows the number of operational satellites for each year. This number must be less than the GEO arc capacity. If it is not, the capture factors must be changed to emphasize larger bus sizes. The spreadsheet then recalculates the number of launches and satellites on orbit. Figure 2.2.1-2 shows the final projected orbital population for both low and high models. The corresponding mix of satellite size classes is shown in figures 2.2.1-3 and 2.2.1-4 for the low and high models, respectively. The allocation of transponder deployments as a function of satellite size class is given in figures 2.2.1-5 and 2.2.1-6 for low and high models, respectively.

This portion of the analysis is iterative and somewhat subjective in nature. There is no definitive basis for picking specific capture factors. However, accurate projections 10 to 25 years in the future are impossible and only rough trends can be identified. The analysis is very effective at spotting these trends. For example, it clearly shows in what timeframe small 24 transponder satellite launches will be forced to stop, regardless of economics and user community pressures, because orbital crowding will become a significant problem. The timing of this orbital saturation varies somewhat because high and low model launch rates are different; though low model bus sizes tend to be smaller, launch rates are still below high model launch rates.

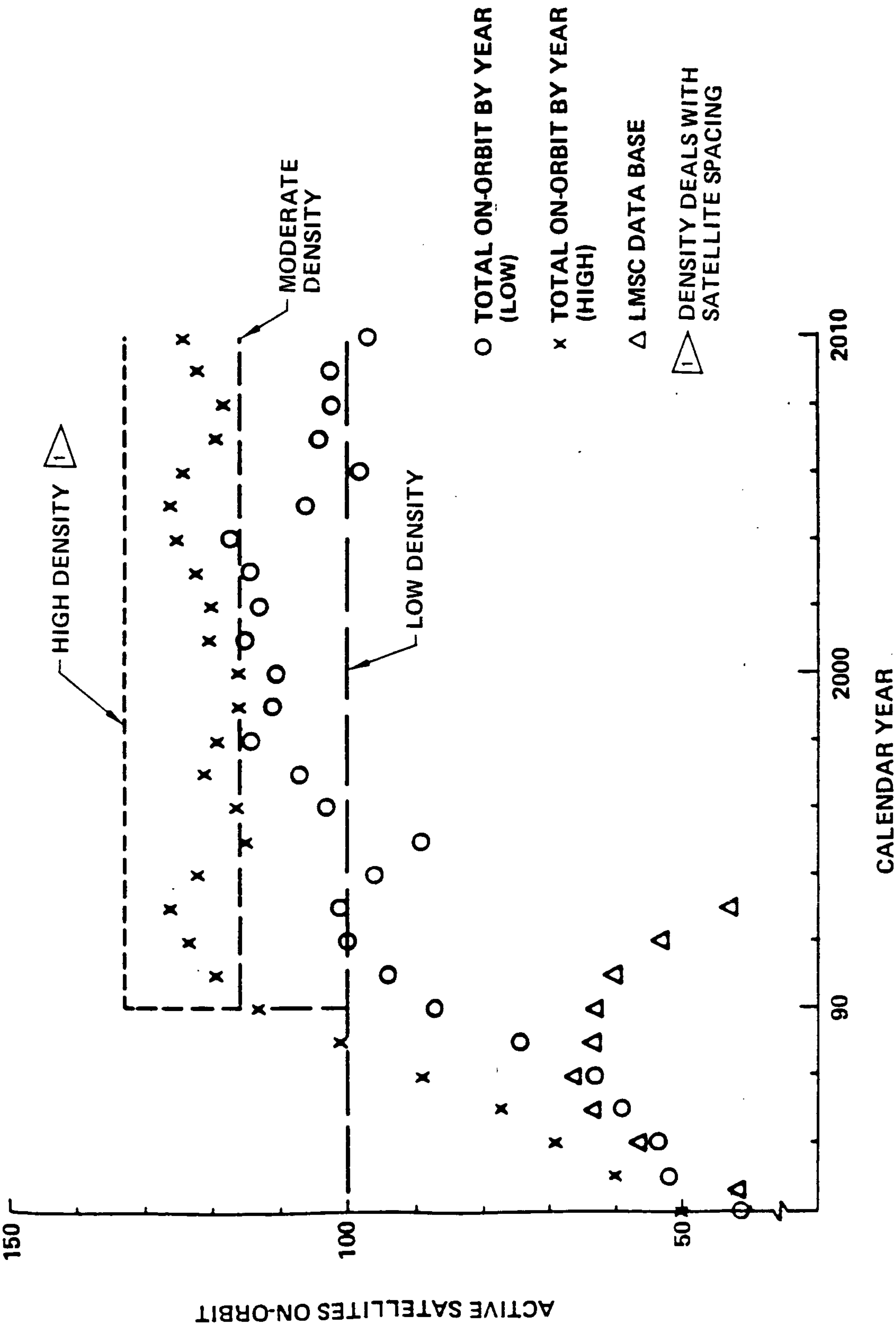

Figure 2.2.1-2. Satellite Population of the Geostationary Arc

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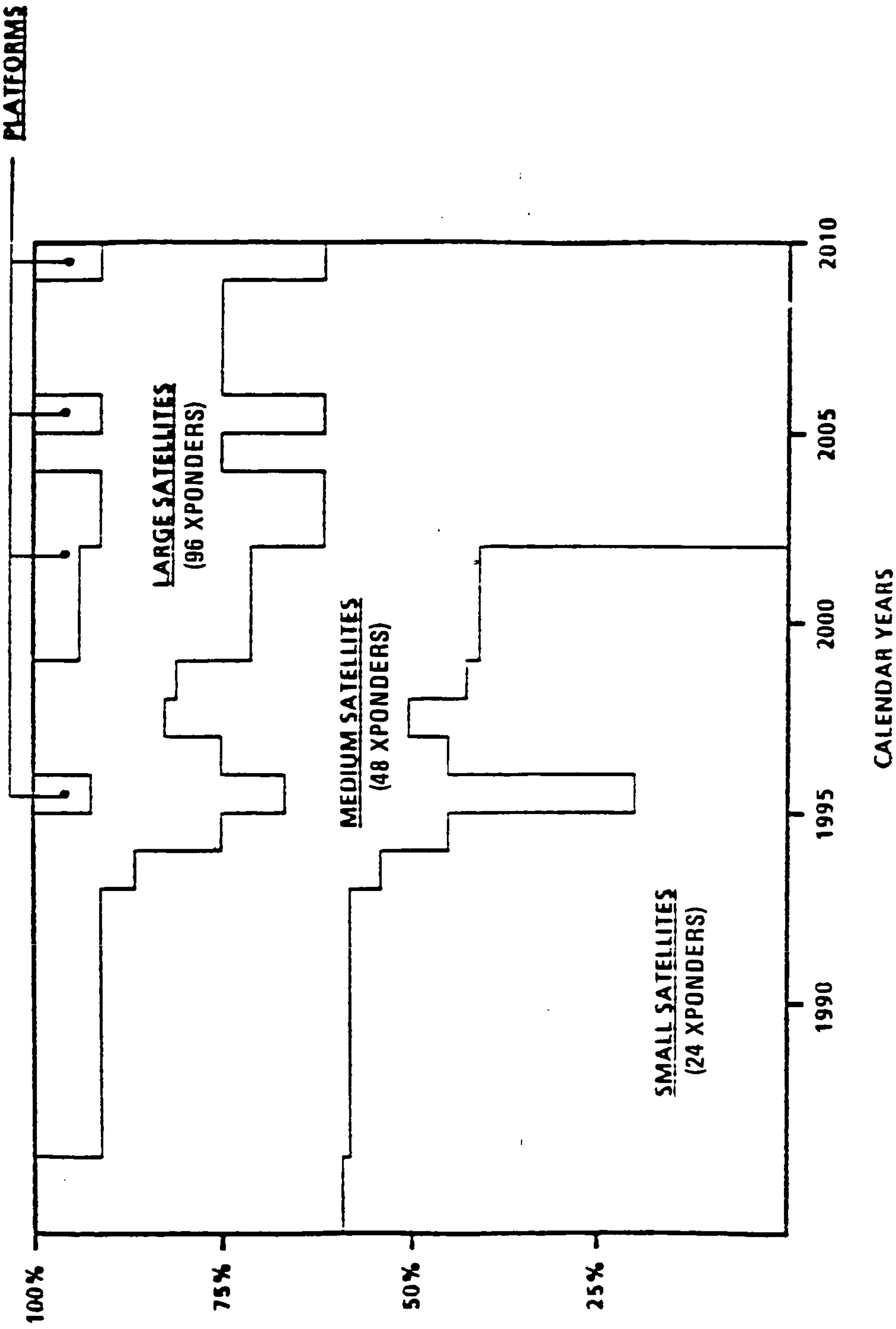

Figure 2.2.1-3 Percent of Communication Satellites Launched by Type (Low Model)

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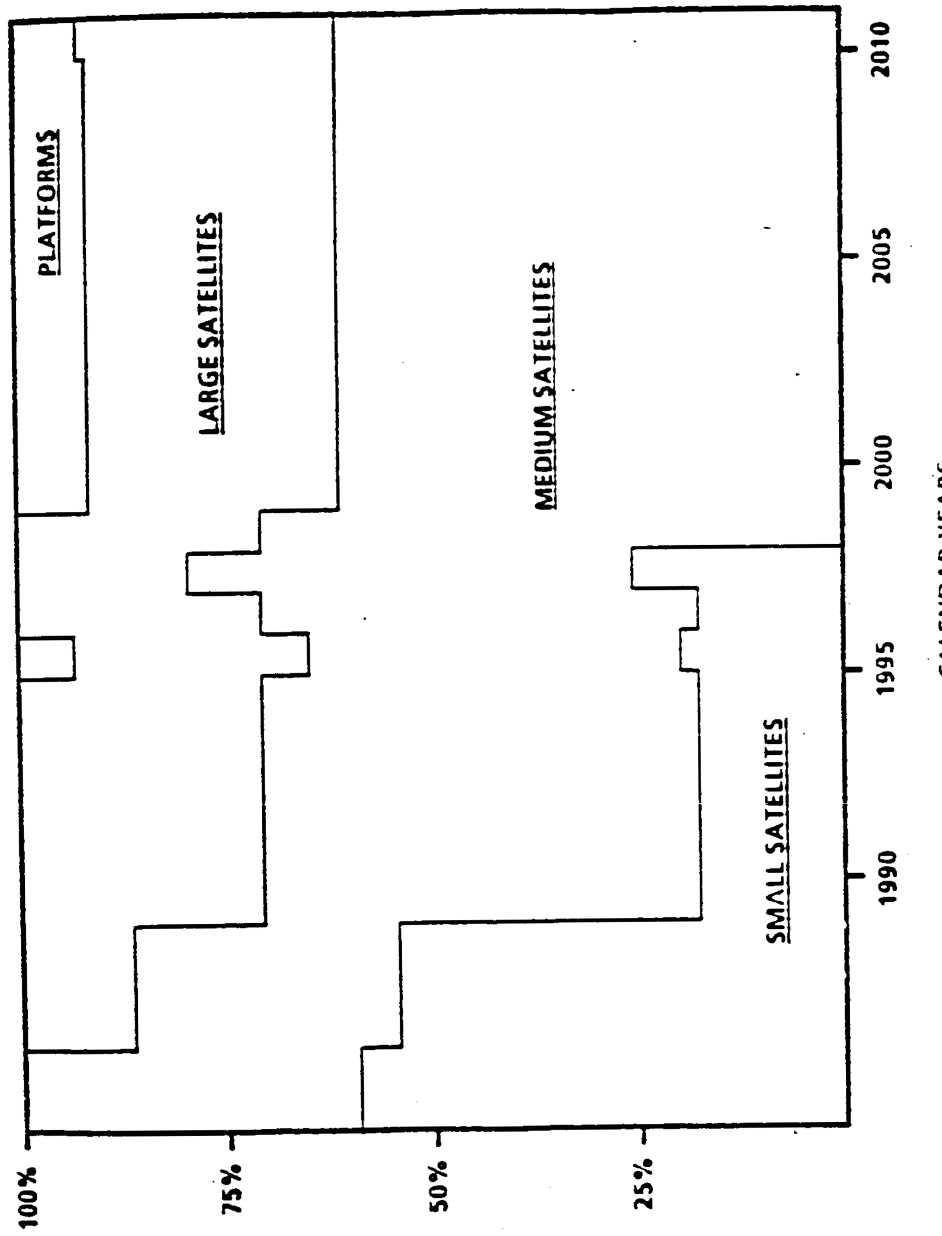

Figure 2.2.1-4 Percent of Communication Satellites by Type (High Model)

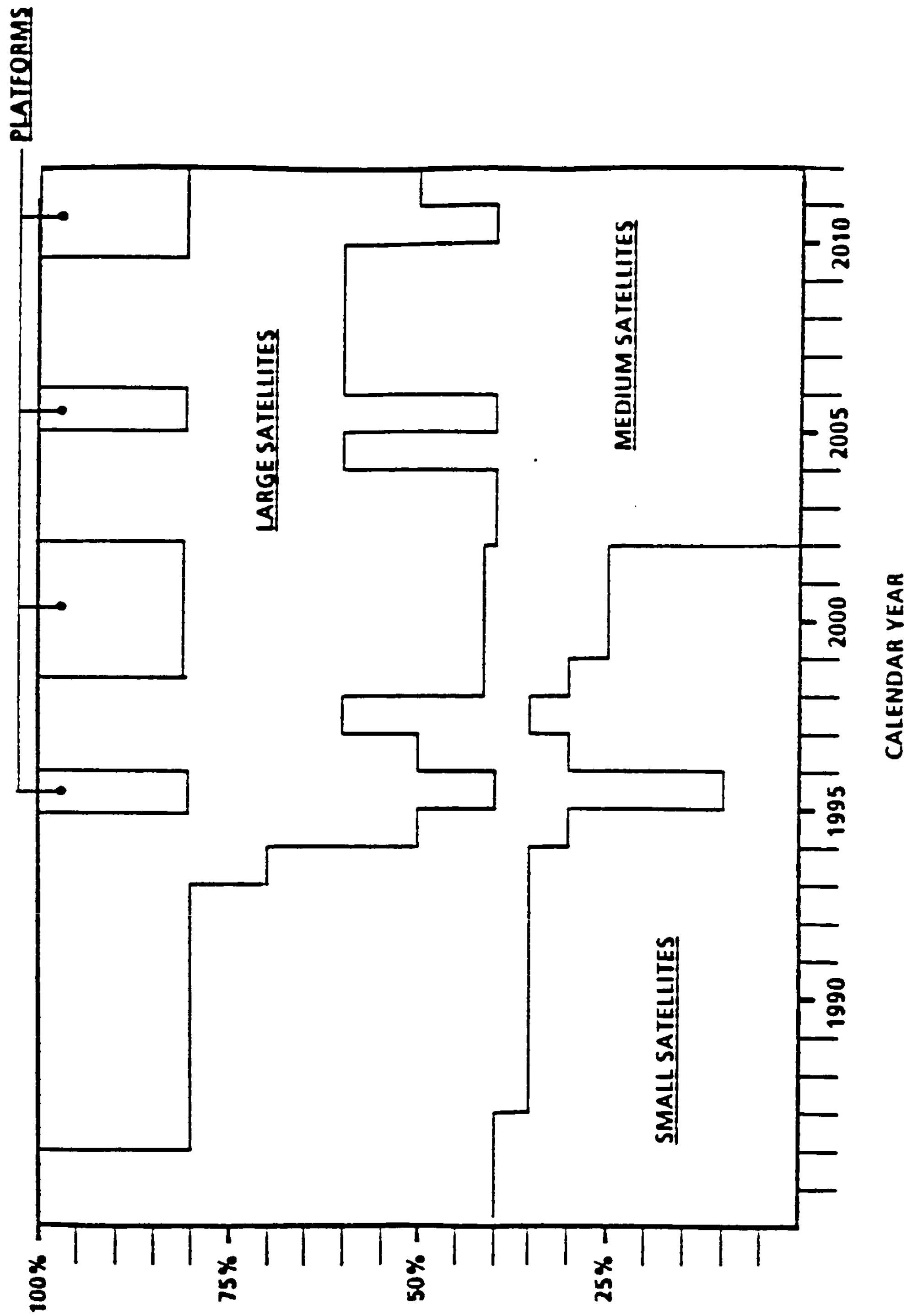

Figure 2.2.1-5 Percent of Communication Transponders by Type (Low Model)

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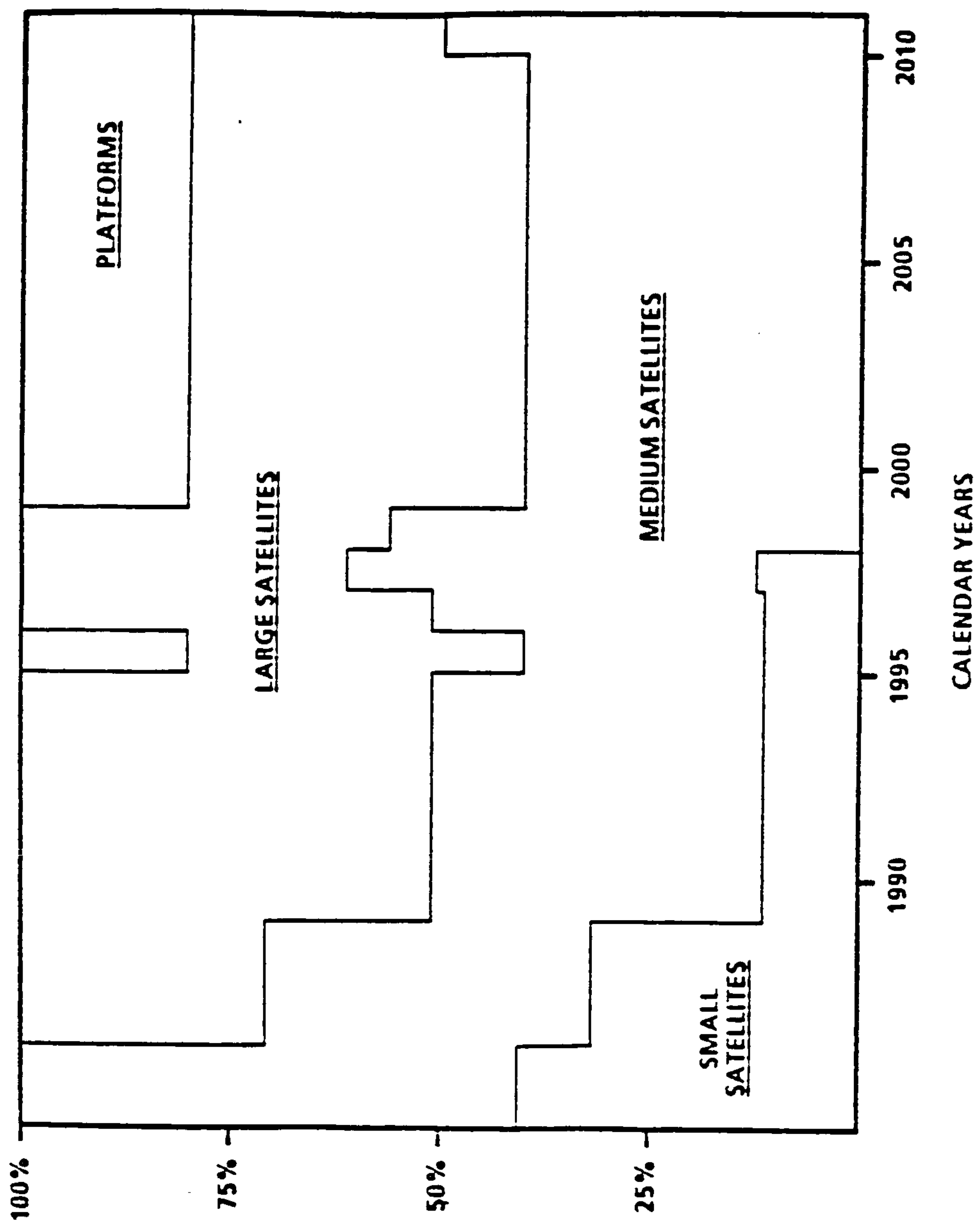

Figure 2.2.1-6 Percent of Communication Transponders Launched by Type (High Model)

The number of available slots in GEO depends on a number of factors. Not all of the GEO arc is usable because it is located in low traffic areas, such as much of Asia and the Pacific Ocean. A usable arc of 200° was assumed. Spacing of satellites along the arc is constrained by interference effects at the ground station from satellites in adjacent slots. Spacing can be narrowed by alternating polarization of each consecutive satellite, and by use of different frequencies and frequency bands. The same slot can also be used for transmission to both northern and southern hemispheres. Usable frequencies are limited by atmospheric absorption problems, technology availability, and other restrictions, such as military communications bands. It was assumed that a spacing of 1.5° would be available by 1990 for the high model, resulting in a maximum of 133 satellites on orbit; the low model maximum was 116 satellites. The communications payloads ground rules and assumptions are summarized in table 2.2.1-1.

Payload Capture

The first two parts of the mission analysis identified how many transponders needed to be deployed and how many and what type of satellites were required to deploy them. The third part of the analysis determined how many of these satellite launches could be captured by OTV, and by extension, what the OTV flight rates would be.

Most of the communications satellites identified in the model are small enough to be launched on current expendable launch vehicles and upper stages. In order to capture these payloads, OTV must demonstrate clear economic advantages over the expendable systems. To do this it must operate as efficiently as possible. This means that the smaller payloads must be multiple manifested.

Multiple manifesting is not applicable to all payloads. The carrier must provide mechanical and electrical interfaces for all payloads, which causes significant design problems. For example, the Shuttle can fit six PAM-D class satellites in its payload bay, but only has enough interfaces for five. There are also operational constraints to how many payloads an OTV could carry; i.e., customers will not be willing to wait for extended periods of time until the OTV is full. This means that the OTV must be selective enough to multiple manifest larger payloads that will fill its capacity quickly and not delay any payload launch dates. It has been assumed that the OTV will carry no more than four satellites, even though it will be able to deliver the mass equivalent of ten or more PAM-D class payloads.

As currently envisioned, all multiply manifested payloads would be brought up together in the Shuttle payload bay. All system checkouts would be conducted on the ground so orbital operations would consist of simply plugging the payload into the

Table 2.2.1-1 Communications Payloads Ground Rules & Assumptions

- FIRST PLATFORM LAUNCH, 192 TRANSPONDER PROTOTYPE IN 1995
  - HIGH MODEL: 1999, 384 TRANSPONDER OPERATIONAL PLATFORM
  - LOW MODEL: 1999, 192 TRANSPONDER OPERATIONAL PLATFORM
    : 2005, 384 TRANSPONDER PROTOTYPE PLATFORM
    : 2008, 384 TRANSPONDER OPERATIONAL PLATFORM
- 24 TRANSPONDER SATELLITES ARE DISCONTINUED
  - HIGH MODEL: 1997 LAST LAUNCH
  - LOW MODEL: 2001 LAST LAUNCH
- ON-ORBIT SATELLITE MIX TO KEEP CONSTELLATION WITHIN:
  - HIGH MODEL: 133 SATELLITES IN TRAFFIC ARC AFTER 1990
  - LOW MODEL: 116 SATELLITES IN HEAVY TRAFFIC ARC AFTER 1992

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carrier and launching the OTV. In an alternate approach, the satellites would be delivered by the Shuttle already attached to the carrier. In both cases the payloads would experience no delays beyond ground-based Shuttle integration delays.

The multiple manifest portion of the payload capture was not done using spreadsheet techniques. Payload combinations exceeding 10,000 lb (including 2000 lb carrier) were manually selected and entered in the spreadsheet output. A limited mission capture function was conducted: the OTV was assumed to be sized to deliver the 20,000 lb platform, which is the largest communications payload. A typical payload combination always included one large satellite (6000 lb) and a number of medium and small ones (3000 lb and 1500 lb, respectively). The total number of multiple manifested payloads was always limited to four.

In the payload capture analysis, all multiple manifest configurations can be captured by OTV. The medium and small satellites that are not multiple manifested are launched using expendable upper stages.

Satellite Sizing Criteria. An evaluation of satellite sizes, weights, and capacity defined four classes of payloads that have been used in this mission model. The 24 transponder satellite is based on the WESTAR 5, which has 24 transponders with a life of 10 years and weighs about 1280 lbm. The INTELSAT V has 42 equivalent transponders and weighs about 2250 lb and the INTELSAT VI has 56 equivalents and weighs 4805 lb. Weight growth, service life, and equivalent transponders of INTELSAT spacecraft is shown in table 2.2.1-2. These transponder weight trends are extrapolated in figure 2.2.1-7.

To size the platforms an analysis of current satellite design resulted in a weight percentage comparison, shown in table 2.2.1-3. Using the NASA Space Systems Technology Model, these weight allocations were scaled to meet 1995 technology growth projections. The weight improvements based on 1995 technology are summarized in table 2.2.1-4. Table 2.2.1-5 shows the resulting weight allocation for a 1995 platform. The percentages shown are referenced to the specific transponder weight of current technology communications satellites. The platform weight allocation shown in table 2.2.1-5 also includes provisions for non-communications payloads such as science and observation equipment. Table 2.2.1-6 summarizes the conversion assumptions between current technology and the 1995 platform. Table 2.2.1-7 shows the subsystem weight allocations for the 192 transponder platform and growth versions to a 384 transponder platform.

Table 2.2.1-2 Intelsat History

Generation	Year	Reference Transponders	Weight(#)	Life	#/xpndr	#/xpndr-Yr
I	1965	1			800	--
II	1967	1			800	--
III	1969	5		5	~270	54
IV	1971	12	1610	7	134	19.2
IVA	1975	20	1740	7	87	12.4
V	1981	42	2250	7	53.6	7.6
VA	1984	63	2395	7	38	5.4
VI	1986	56	4805	10	85.8	8.6
VII	(?)	96	~5000	10	~52.1	5.2

OTV-1836

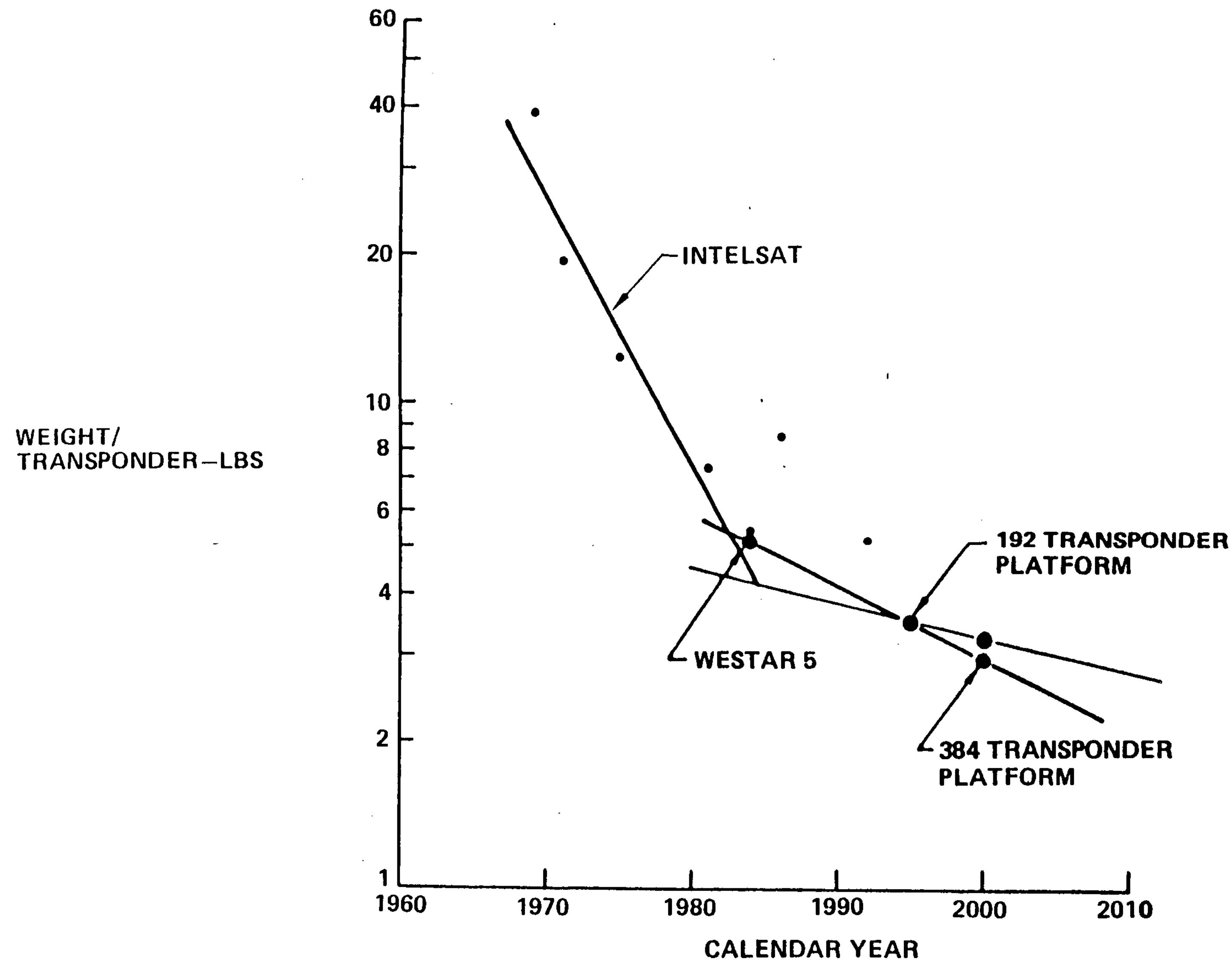

Figure 2.2.1-7 Trend in Transponder Weights

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Table 2.2.1-3 Communication Satellite Subsystems Weights

Communication Package	19%
Structure	36%
Solar Array	8%
Thermal, Avionics, EPS	11%
Altitude Control	26%
Total Weight	100%

[Typical Communications Satellite e.g., Intelsat, etc.]

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Table 2.2.1-4 Subsystem Weight Improvements with 1995 Technology

Communication Package Efficiency	+50%
Structural Strength	+30%
Solar Array Weight	+83%
Thermal, Avionics, EPS Weight	+20%
Attitude Control	+65%

* NASA Space Systems Technology Model, Vol. II A & B (NASA OAST, Code RS, Hq NASA, Jan. 84)

OTV-1827

Table 2.2.1-5 Platform Weights (192 XPNDRS)

Communication Package	12.7%
Structure	27.7%
Solar Array	1.3%
Thermal, Avionics, EPS*	8.8%
Attitude Control	16.6%
Subtotal	67.0%
Overhead for Science/OBS.	5.0%
Interplatform Comm.	2.0%
Science/Observation Pkgs.	10.0%
Total Weight	84.0%

* [Avionics weight stays constant]

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Table 2.2.1-6 Comparisons/Conclusions

<u>Current</u> Comm Satellite		
WESTAR 5	=	1280 #
XPNDRS	=	24
W/T	=	53.3 #/Trans.
Platform, <u>1995</u> Technology		
Specific Weight	=	84%
Todays Weight per XPNDRS	=	53.3 #
●● Platform W/T	=	44.8 #/Trans (in 1995)

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Table 2.2.1-7 Platform Weight Growth

	192 Transponder	384 Transponder	
Wt/XPDR	(35.8) (6,871)	(33) (12,672)	(30) (11,520)
Communications Package	1,300	2,400	2,180
Structure	2,837	5,230	4,760
Solar Aray	133	242	224
Thermal, Avionics, EPS, etc.	901	1,660	1,510
Attitude Control	1,700	3,140	2,850
Inter Platform Comm.	205	205	205
Overhead for SCI/OBS.	512	512	512
Science/Observation Pkgs.	1,024	1,024	1020
(Wt/XPDRS - 44.8) Subtotal	8,612	14,407	13,261
Weight Growth (10%)	861	1,440	1,326
Servicing Provisions (5%)	430	720	663
Contingencies (5%)	430	720	663
TOTAL	10,333	17,287	15,913

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Satellite Servicing Effects. The communications model assumed that satellites would be actively serviced during the OTV mission model period. The effects of servicing, including changes in lifetime, are summarized in tables 2.2.1-8 and 2.2.1-9 for low and high models, respectively. Satellite servicing is discussed in detail in section 2.2.2.

Summary

An analysis was conducted to forecast communications satellite launches through the year 2010. The results, given in tables 2.2.1-10 and 2.2.1-11 for low and high models respectively, showed that the onset of GEO arc saturation would cause a requirement for communications platforms to keep the satellite population level. In both high and low models the satellite population rose to capacity and then leveled off.

There is also a cyclic effect on the on-orbit population due to the large number of small satellites currently (1984) being launched. Replacement of these satellites (10 year life) will occur before OTV becomes fully operational and will introduce a large number of small satellites into the on-orbit population. These small satellites will take a disproportionately large percentage of the arc capacity, forcing later customers to use platforms. As more platforms become operational and small satellites are decommissioned, the on-orbit population will drop slightly. Demand for more transponders will slowly bring the population back to capacity.

A point design of a GEO platform was conducted in parallel with the mission analysis. This design analysis showed that the largest communications satellite in the 2010 timeframe will be a platform weighing approximately 20,000 lb.

Table 2.2.1-8 Satellite Life & Servicing Assumptions (Low Model)

Low Model	Platforms	Large Sats	Med Sats	Small Sats
• Design Life	Lg - 15 years Sm - 10 years	10 years	10 years	10 years
• Mass	Lg - 20,000 lbs. Sm - 10,000 lbs.	6000 lbs	3000 lbs	1500 lbs
• Servicing - Refuel - Update	3 yr interval 3 yr interval	6 yr interval -	- -	- -
• Unmanned Events	All refueling 50% of updates	All refueling -	- -	- -
• Manned Events	50% of updates	-	-	-
• Service Mass (% of Satellite) } Refuel Update	5% 10%	10% -	- -	- -

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Table 2.2.1-9 Satellite Life & Servicing Assumptions (High Model)

High Model	Platforms	Large Sats	Med Sats	Small Sats
• Design Life	15 years	12 years	10 years	10 years
• Mass	Lg - 20,000 lbs. Sm - 10,000 lbs.	6000 lbs	3000 lbs	1500 lbs
• Servicing - Refuel - Update	3 yr interval 3 yr interval	4 yr interval 8 yr only	6 yr only -	- -
• Unmanned Events	All refueling 50% of updates	All refueling -	All refueling -	- -
• Manned Events	50% of updates	All updates	-	-
• Service Mass (% of Satellite) } Refuel Update	5% 10%	7% 10%	10% -	- -

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Table 2.2.1-10 Communications Model (Low)

COMM LOW MISSION MODEL	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
TRANSPONDERS TO BE LAUNCHED	416	748	420	504	360	552	620	364	372	384	388	720	1052	678	760	626	904	842	632	618	580	542	904	1306	732	1014	888
TRANSPONDER INCREASE (DEMAND)	300	500	200	300	200	400	500	200	200	100	100	300	300	250	250	250	250	250	250	250	250	250	250	250	250	250	250
TRANSPONDERS AT LIFE END (10 YEAR LIFE)	240	216	192	168	144	120	144	168	192	192	408	744	408	504	360	552	600	360	360	288	288	720	1032	672	744	624	792
TRANSPONDERS ON-ORBIT (CUMMULATIVE)	1200	1700	1900	2200	2400	2800	3300	3500	3700	3800	3900	4200	4500	4750	5000	5250	5500	5750	6000	6250	6500	6750	7000	7250	7500	7750	8000
PLATFORM LAUNCHES	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	0	1	0	0	0	1	1
TRANSPONDERS @192	0	0	0	0	0	0	0	0	0	0	0	192	0	0	0	192	192	192	192	192							
@384	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	384	0	0	0	384	384
SATELLITES AT LIFE END	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1
LARGE SATELLITE LAUNCHES	0	0	1	1	0	1	1	0	0	1	1	1	3	2	2	1	2	2	1	1	2	0	3	4	3	2	1
TRANSPONDERS @96	0	0	96	96	0	96	96	0	0	96	96	96	288	192	192	96	192	192	96	96	192	0	288	384	288	192	96
SATELLITES AT LIFE END	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	1	1	3	2	2	1	2	2
MEDIUM SATELLITE LAUNCHES	5	9	3	5	4	5	6	4	4	2	2	5	9	5	7	4	5	6	7	6	8	3	14	19	13	9	8
TRANSPONDERS @48	240	432	144	240	192	240	288	192	192	96	96	240	432	240	336	192	240	288	336	288	384	144	672	912	624	432	384
SATELLITES AT LIFE END	0	0	0	0	2	2	2	2	2	5	9	3	5	4	5	6	4	4	2	2	5	9	5	7	4	5	5
SMALL SATELLITE LAUNCHES	7	13	7	7	7	9	9	7	7	4	4	8	13	10	9	6	7	7									
TRANSPONDERS @24	168	312	168	168	168	216	216	168	168	96	96	192	312	240	216	144	168	168									
SATELLITES AT LIFE END	10	9	8	7	2	1	2	3	4	7	13	7	7	7	9	9	7	7	4	4	8	13	10	9	6	7	7
TRANSPONDERS NOT LAUNCHED	8	4	12	0	8	0	20	4	12	16	20	8	20	6	16	2	12	22	8	42	4	14	24	10	20	6	16
SATELLITES LAUNCHED	12	22	11	13	11	15	16	11	11	7	7	15	25	17	18	12	15	16	9	8	10	4	17	23	16	12	10
SATELLITES REPLACED	7	10	9	8	7	4	3	4	5	6	12	22	11	13	11	15	16	11	11	7	7	15	25	17	18	12	15
SATELLITE INCREASE	5	12	2	5	4	11	13	7	6	1	-5	-7	14	4	7	-3	-1	5	-2	1	3	-11	-8	6	-2	0	-5
SATELLITES ON-ORBIT	40	52	54	59	63	74	87	94	100	101	96	89	103	107	114	111	110	115	113	114	117	106	98	104	102	102	97

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Table 2.2.1-11 Communications Model (High)

COMM HIGH MSM MODEL	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
TRANSPONDERS TO BE LAUNCHED	516	652	720	692	780	864	828	540	480	500	612	816	1040	1136
TRANSPONDER INCREASE (DEMAND)	300	400	500	500	600	700	700	400	300	300	400	300	400	400
TRANSPONDERS AT LIFE END	240	216	192	168	144	120	144	168	192	192	504	648	720	672
TRANSPONDERS ON-ORBIT (CUMMULATIVE)	1200	1600	2100	2600	3200	3900	4600	5000	5300	5600	6000	6300	6700	7100
PLATFORM LAUNCHES	0	0	0	0	0	0	0	0	0	0	0	1	0	0
TRANSPONDERS @192	0	0	0	0	0	0	0	0	0	0	0	192		
@384	0	0	0	0	0	0	0	0	0	0	0		0	0
SATELLITES AT LIFE END	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LARGE SATELLITE LAUNCHES	0	0	2	2	2	4	4	2	2	2	3	3	5	5
TRANSPONDERS @96	0	0	192	192	192	384	384	192	192	192	288	288	480	480
SATELLITES AT LIFE END	0	0	0	0	0	0	0	0	0	0	0	2	2	2
MEDIUM SATELLITE LAUNCHES	6	7	6	6	7	8	7	6	5	5	5	5	9	11
TRANSPONDERS @48	288	336	288	288	336	384	336	288	240	240	240	240	432	528
SATELLITES AT LIFE END	0	0	0	0	2	2	2	2	2	6	7	6	6	7
SMALL SATELLITE LAUNCHES	9	13	10	8	10	4	4	2	2	2	3	4	5	5
TRANSPONDERS @24	216	312	240	192	240	96	96	48	48	48	72	96	120	120
SATELLITES AT LIFE END	10	9	0	7	2	1	2	3	4	9	13	10	8	10
TRANSPONDERS NOT LAUNCHED	12	4	0	20	20	0	4	20	8	20	12	0	16	8
SATELLITES LAUNCHED	15	20	10	16	19	16	15	10	9	9	11	13	19	21
SATELLITES REPLACED	7	10	9	8	7	4	3	4	5	6	15	20	10	16
SATELLITE INCREASE	8	10	9	8	12	12	12	6	4	3	-4	-7	1	5

COMM HIGH MSM MODEL	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
TRANSPONDERS TO BE LAUNCHED	1060	1192	1304	1224	952	920	696	736	944	1272	[illegible]	1472	1296
TRANSPONDER INCREASE (DEMAND)	400	400	400	400	400	400	400	400	400	400	400	400	400
TRANSPONDERS AT LIFE END	768	864	816	528	480	288	312	528	840	936	1056	864	1296
TRANSPONDERS ON-ORBIT (CUMMULATIVE)	7500	7900	8300	8700	9100	9500	9900	10300	10700	11100	11500	11900	12300
PLATFORM LAUNCHES	0	1	1	1	1	1	0	0	0	1	1	1	1
TRANSPONDERS @192													
@384	0	384	384	384	384	384	0	0	0	384	384	384	384
SATELLITES AT LIFE END	0	0	0	0	0	0	0	0	0	0	0	1	0
LARGE SATELLITE LAUNCHES	5	4	5	4	3	3	3	3	4	5	5	6	3
TRANSPONDERS @96	480	384	480	384	288	288	288	288	384	480	480	576	336
SATELLITES AT LIFE END	4	4	2	2	0	0	2	3	3	5	5	5	4
MEDIUM SATELLITE LAUNCHES	12	8	9	9	5	5	8	9	11	8	10	10	13
TRANSPONDERS @48	576	384	432	432	240	240	384	432	528	384	480	480	624
SATELLITES AT LIFE END	8	7	6	5	5	5	5	9	11	12	8	9	9
SMALL SATELLITE LAUNCHES													
TRANSPONDERS @24													
SATELLITES AT LIFE END	4	4	2	2	3	3	4	5	5	0	0	0	0
TRANSPONDERS NOT LAUNCHED	24	40	8	24	40	8	24	16	32	24	16	32	0
SATELLITES LAUNCHED	17	13	15	14	9	9	11	12	15	14	16	17	17
SATELLITES REPLACED	19	16	15	10	9	7	8	11	17	19	17	13	15
SATELLITE INCREASE	-2	-3	0	4	0	2	3	1	-2	-5	-1	4	2

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2.2.2 GEO Servicing

This section explains the rationale behind satellite servicing and describes two different servicing approaches including a cost analysis (2.2.2.1). One of these approaches (LEO-based servicing) was used in the Revision 7 mission model and other previous studies. However, the second approach (GEO-based servicing) was found to be more cost effective and is described in considerable detail in the second section (2.2.2.2).

2.2.2.1 Servicing Concepts

Servicing of GEO satellites is an important element of the OTV mission model. Because of its potentially large impact on OTV flight rates, and therefore economics, it is important to choose the most efficient servicing approach.

Satellite servicing is attractive because it can extend the useful lifetime of operational satellites. This is accomplished by replenishing expendable fluids (RCS propellant, sensor cryogens, etc.), repairing failed spacecraft systems (ref. Solar Max), or updating spacecraft technology (GEO platforms) or adding capability. On-orbit servicing capability will lead to reduced spacecraft costs and risk, and increased operational flexibility.

Servicing will normally take the form of routine maintenance and repair operations but will occasionally involve unscheduled or emergency repair of failed spacecraft subsystems. These servicing tasks vary in complexity, difficulty, and cost, which determines whether the mission is performed manned or unmanned.

Unmanned servicing is assumed to use an OMV or OMV-derivative vehicle equipped with manipulators and propellant transfer equipment. The present OMV design does not include these characteristics but a GEO version should be available in the OTV time frame.

Servicing missions can be centered around either LEO or GEO transportation nodes. The selected approach has a strong impact on OTV requirements and flight rates, for both manned and unmanned servicing.

With LEO-based servicing all mission hardware elements are returned to either the Space Station or the Shuttle after each mission. With GEO-based servicing hardware elements are left in GEO to the extent practical after each mission. Thus, each mission takes advantage of space assets delivered during previous missions and, in turn, builds up the servicing capability available for following missions. This approach makes very efficient use of OTV transportation capacity.

Unmanned Servicing

LEO-based unmanned servicing includes the reference approach described in the NASA Rev. 7 mission model and depicted in figure 2.2.2-1. With this approach the OTV carries the OMV servicer to GEO for each OMV servicing mission and returns it to LEO after the servicing is completed. The OMV is assumed to service four satellites during each mission over a 15 day period. Satellite spacing is 20°. All GEO maneuvers are done by OMV for a total of 120° of phase (longitude) change between OTV separation and OTV rendezvous.

The principal problem with this approach is that the ratio of replacement mass to satellite mass is relatively high (typically 10-15%) and the delivery cost (on a pound for pound basis) of the replacement mass is many times that of a new satellite delivery. This happens because the 4510 lbm inert weight of the OMV must be carried round trip to and from GEO to deliver 1700 lbm of replacement mass. The net effect is that, in many cases, it would be less expensive to deliver new satellites instead of servicing existing ones.

The uncertain economics of LEO-based servicing endanger the whole concept of on-orbit servicing. Commercial users especially are unlikely to adopt servicing if the associated costs are too high to produce economic benefits.

GEO-basing eliminates many of the cost penalties associated with LEO-based unmanned servicing as shown in figure 2.2.2-2. As in LEO-based servicing, an OMV is used to service four satellites per mission. The principal difference is that the OMV remains in GEO after the mission servicing tasks are completed. In this way the inert weight of the OMV is delivered to GEO only once, with substantial savings in OTV propellant costs over the period of the mission model. Since servicing mass requirements are relatively low and generic in nature (i.e., mostly N_2H_4 propellant) it is possible to deliver servicing propellants in conjunction with other scheduled OTV launches, thus saving on launch costs. In order to maintain analytic consistency, the same mission profile was used for both GEO- and LEO-basing analyses.

The OMV is stored in GEO at a service module that includes a propellant tank farm and equipment module storage. The service module allows shutdown of the OMV avionics while it is not in use, as well as battery charging and propellant replenishment. The service module can be designed to accommodate growth to manned GEO capability. The principal resulting design scars are an oversized solar array and an integral docking module/airlock/storm shelter.

The principal drawbacks of GEO-based servicing are higher up-front acquisition costs. These costs are quickly paid back through reduced operational costs. It should be

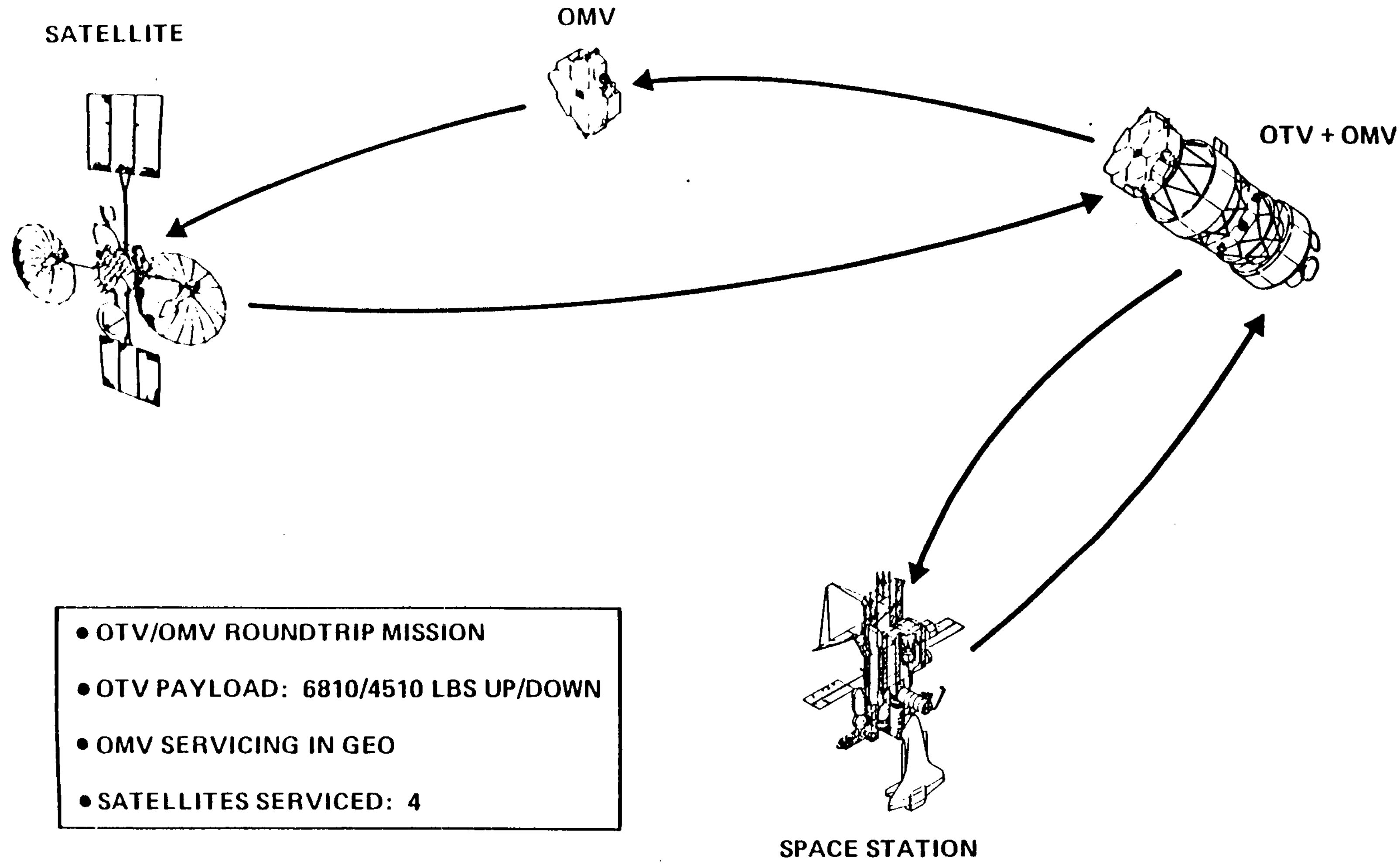

Figure 2.2.2-1 Unmanned Servicing (LEO-Based)

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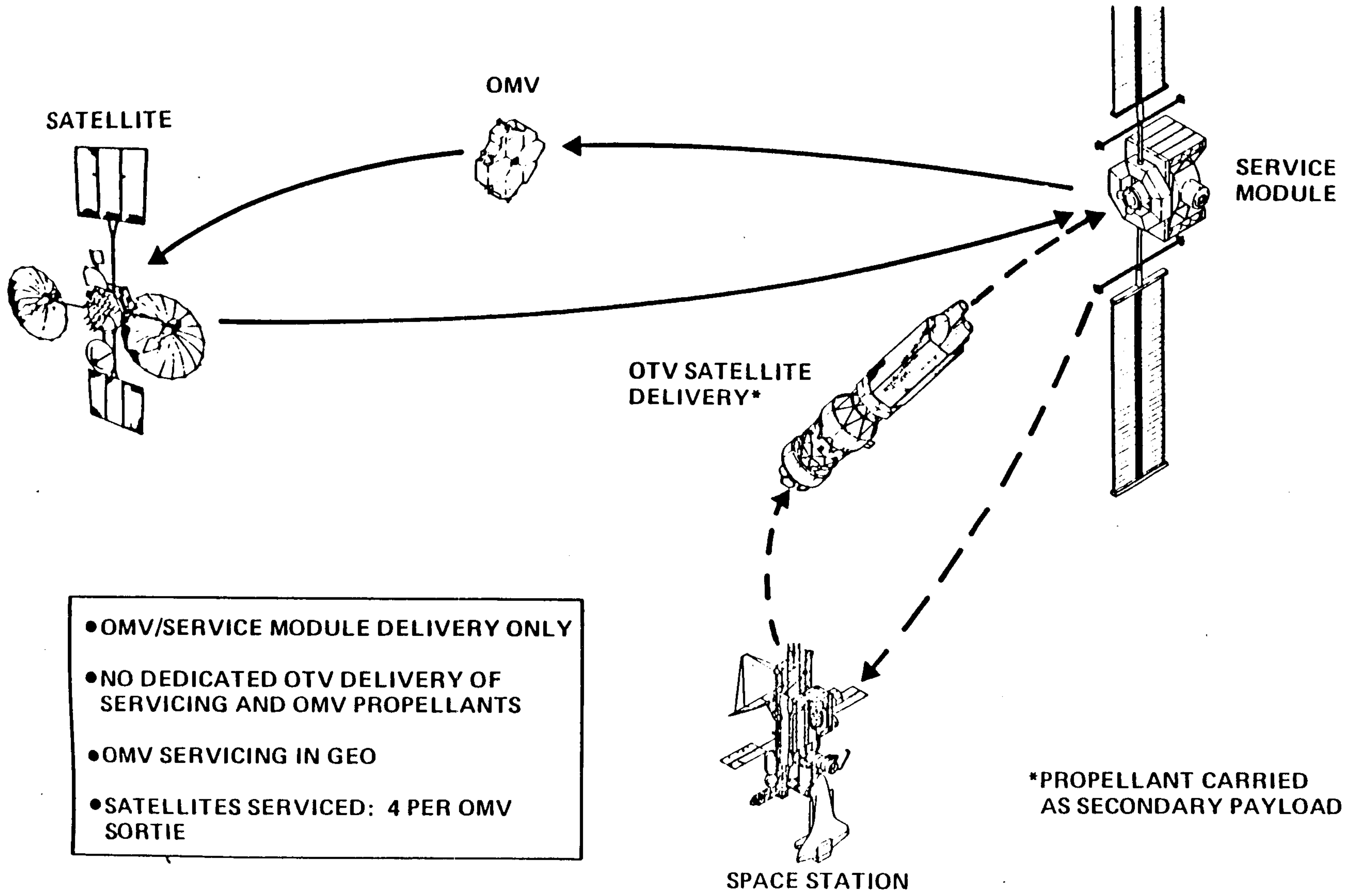

Figure 2.2.2-2 Unmanned Servicing (GEO-Based)

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noted that GEO-based servicing can be accomplished with either Mobile GEO Servicing Station (MGSS) or self-contained manned servicing approaches, so the unmanned servicing approach (LEO- or GEO-basing) could be selected independently from the manned servicing approach.

Unmanned servicing mission characteristics are given in table 2.2.2-1 for the GEO-based approach. Requirements for LEO-based servicing are similar but are manifested differently. The servicing mass estimates are based on a fixed percentage replacement (5% - 10%) of satellite mass at each scheduled servicing interval (3-5 years), with some consideration given to the technology level of the satellite being serviced. The servicing analysis assumed an average replacement mass value, based on the complete mission model.

OMV propellant consumption rate estimates were based on the reference OMV GEO mission (425 lbm delivered to each of 4 satellites separated by 20°). The OMV mission lasts 15 days: a 3 day transfer time between satellites (125 fps each) with a 6 day return time (185 fps), for a total mission delta-V of 560 fps. In addition to the transfer burns (assuming MMH-N_2O_4 with 310 sec Isp), a terminal burn using cold gas thrusters (60 lbm GN_2) is required at each rendezvous.

Propellants used during OMV maneuvers must be replenished. Both OMV propellant and satellite servicing masses can be manifested as secondary payloads during other regularly scheduled satellite deliveries. These requirements have been incorporated in the OTV launch manifest and are included in the cost analysis, discussed later.

OMV maintenance is assumed to occur during the lengthy GEO phasing coast periods required by manned missions.

System Evolution

The principal servicing mission approaches and evolutionary paths are shown in figure 2.2.2-3 for the nominal model, in which both GEO-based and LEO-based servicing grow to a common GEO Space Station configuration. Variations on these evolutionary paths, such as GEO-based unmanned servicing followed by LEO-based manned servicing (MOTV), are not shown.

For GEO-based servicing, a man-tended habitat/work station is launched and mated with the unmanned service module. This IOC configuration is used until a permanent GEO presence is required, at which point additional habitat modules are added. With LEO-based servicing, manned and unmanned operations do not use common hardware elements and missions are conducted independently. All servicing missions remain based at LEO until deployment of the GEO Space Station. At this point the mission

Table 2.2.2-1 Unmanned Servicing Definition (GEO-Based)

- OMV SERVICES 4 SATELLITES PER OTV FLIGHT ($20^o/20^o/20^o$ PHASE SEPARATION PROFILE)
- UNMANNED SATELLITE SERVICING (NOMINAL MODEL)
  - ANNUAL AVERAGE: 4 OMV MISSIONS (16 SATELLITES)
  - ANNUAL MAXIMUM: 6 OMV MISSIONS (24 SATELLITES)
- SATELLITE REFUELING MASS: 1700 LBS/OMV MISSION (425 LBS/SATELLITE)
- OMV CONSUMPTION RATES
  - GN_2: 300 LBS/SERVICING MISSION (5 RENDEZVOUS)
  - MMH–N_2O_4: 300 LBS/SERVICING MISSION (560 FPS TOTAL TRANSFER ΔV)
- ANNUAL CONSUMABLES REQUIREMENTS
  - GN_2: 1200–1800 LBS (OMV AVERAGE/MAX.)
  - MMH–N_2O_4: 1200–1800 LBS (OMV AVERAGE/MAX)
  - N_2H_4: 6800–10200 LBS (SATELLITES AVERAGE/MAX)
- OMV HELIUM PRESSURANT REQUIRES STORAGE TANK WITH PUMP AT MGSS
- OMV MAINTENANCE PERFORMED DURING MANNED SERVICING MISSION AT MGSS
- SERVICING PROPELLANT DELIVERED TO MGSS AS OTV SECONDARY PAYLOAD

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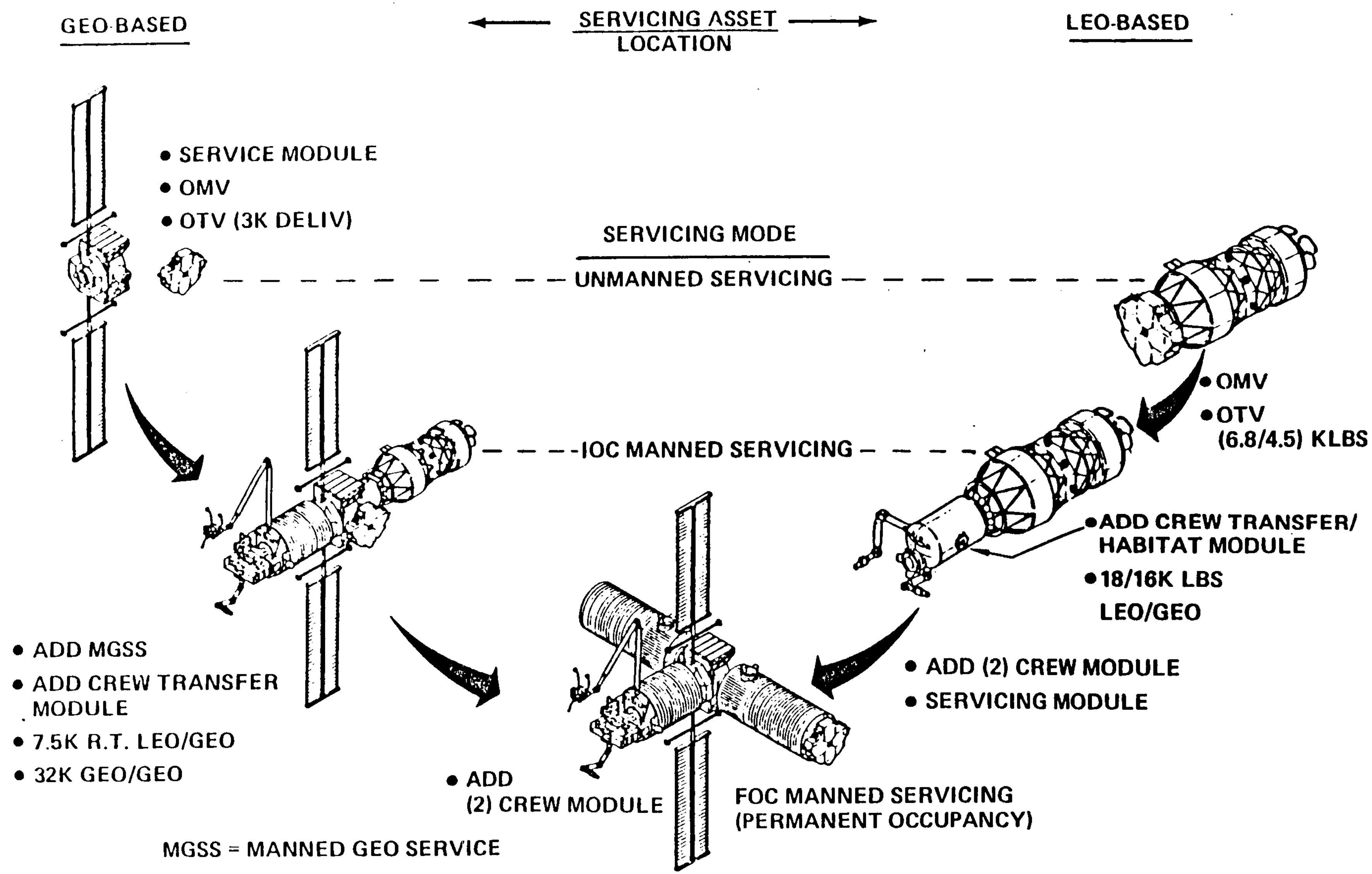

Figure 2.2.2-3 Servicing Mission Approaches and Evolution

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characteristics converge with GEO-based servicing. The principal difference is that the MOTV (LEO-based) capsule is oversized for the 4 times yearly crew rotation flights.

Exclusive GEO-based servicing provides the most efficient transition to manned servicing with lower operational costs. However, LEO-based servicing has lower up-front acquisition costs and operational complexity. One important factor in determining the most cost-effective manned mission approach is manned flight frequency, and consequently, the time period between initial operational capability (IOC) and full operational capability (FOC). Cost analysis of the nominal mission model shows GEO-based servicing (MGSS) to be the most cost-effective approach.

A new reference manned mission was developed to allow a comparison between manned mission approaches. This reference mission replaces the Grumman reference 8 S-1 mission which had been used previously in Rev. 7.

The mission model indicates there will be no more than four satellites requiring manned servicing before 2002, when the GEO Space Station is scheduled to go on line. These servicing missions are primarily routine maintenance/updates and will be scheduled well in advance so that satellites to be serviced can be located in close proximity to each other. This reduces required on-orbit delta-V and total mission time. The new mission profile is depicted in figure 2.2.2-4. Mission characteristics are as follows:

a. Servicing of 4 satellites per mission.
b. Satellites located in two constellations.
c. Constellations 90° apart.
d. Satellite pairs within each constellation 10° apart.
e. 5 phasing orbits between constellations.
f. 2 phasing orbits between satellites within constellations.
g. 3 satellites require routine maintenance/update only.
h. 1 satellite also requires additional repairs.
i. 24-hour servicing time per satellite.
j. Repair tasks require an additional 24 hours.
k. Average 6-hour GEO return phasing for ascending node alignment.
l. Worst case return transfer/phasing orbit.
m. 2-day contingency.

Manned Servicing

The two manned servicing approaches are discussed below. LEO-based servicing has been analyzed extensively in the Grumman MOTV studies (reference 8). It is

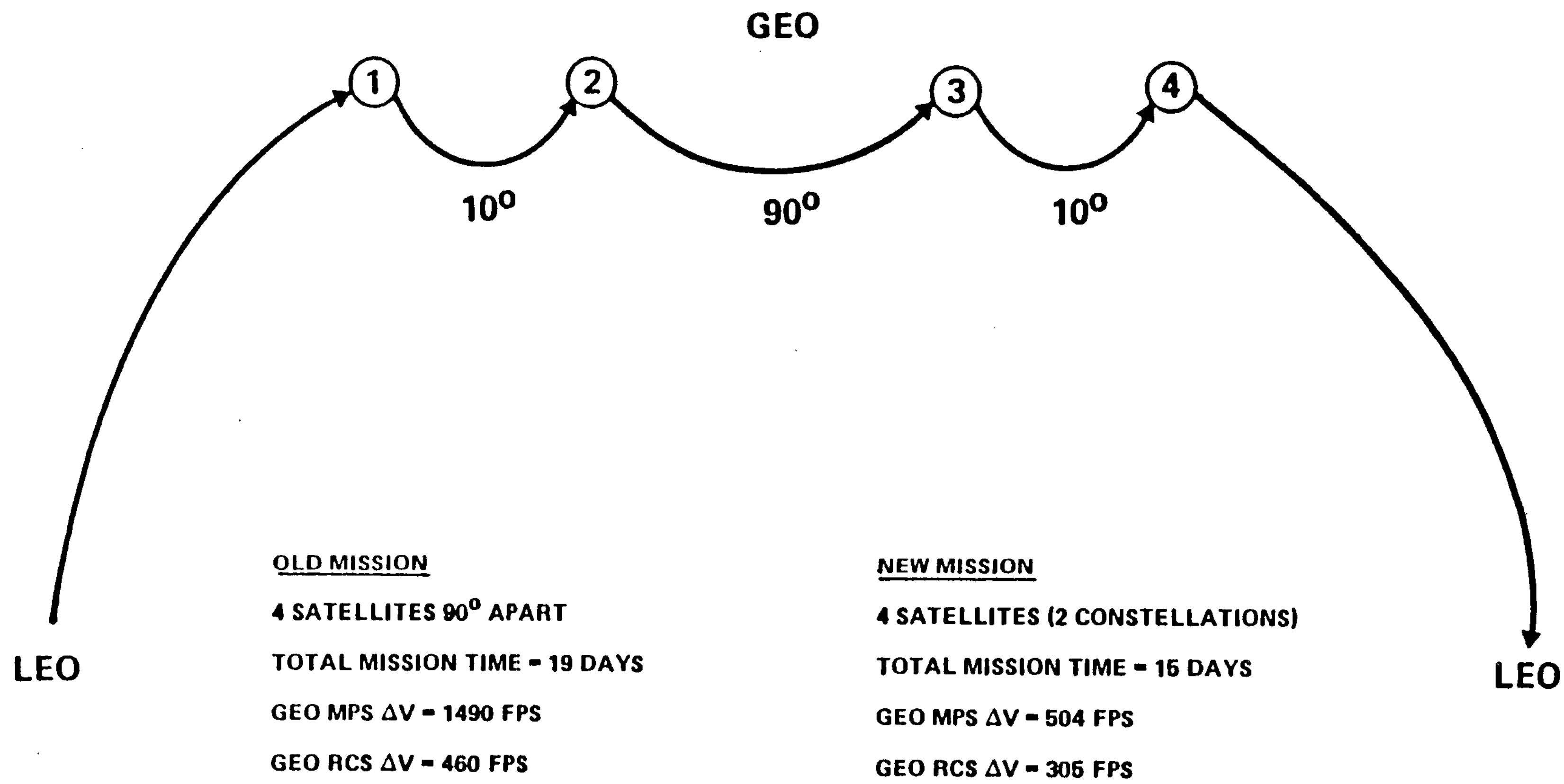

Figure 2.2.2-4 Revised Reference Manned Mission

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described briefly here, including updated weights that were developed to ensure consistency with the MGSS GEO-based approach in the costing analysis. The MGSS concept is also described in more detail later in this section.

The MGSS approach to manned servicing, shown in figure 2.2.2-5, has a habitat/workstation/service module located permanently in GEO or near-GEO orbit and a manned transfer system (MTS) consisting of a crew module and a man rated OTV. This facility has all the general purpose equipment (GPE) required for on-orbit operations, in addition to storage for spacecraft equipment modules and propellants. Because the MGSS hardware is launched only once and does not need to be returned to low Earth orbit, it can be made larger and more sophisticated than an MOTV manned cab without pushing OTV performance requirements. It is an inherently more capable system.

After docking at GEO the crew transfers from the MTS to the MGSS habitat. Though not manned, the OTV remains active to provide guidance and main propulsion (i.e., GEO phasing maneuvers). RCS is provided by the MGSS. In the reference manned mission profile the MGSS is moved to four different satellite locations prior to MTS separation and return to LEO. In a growth MGSS (i.e., permanent GEO Space Station) the MGSS remains in an orbit slightly above GEO and slowly drifts past all GEO satellites. Servicing is accomplished with an OMV, manned OMV (using an MGSS transfer cab), or an MMU while the satellite is near the MGSS.

The estimated weight of the MGSS transfer capsule is 5700 lb. The 7500 lb round trip figure is used to account for other payloads such as equipment modules or logistics provisions. Old satellite equipment modules would not normally be returned to LEO with the manned crew (weight-limited mission), but would be mounted on a pallet for later return to LEO on a non-weight-limited OTV flight.

The MGSS has three major components: a service module and GEO OMV, which are deployed together, and a habitat/workstation which is deployed later. Principal features are identified in figure 2.2.2-6, including MGSS and manned OTV weight summaries. The OMV is a special design modified for GEO operations including remote propellant transfer equipment and rechargeable batteries. The service module performs many functions. It provides power for both the habitat and the OMV, storage for servicing equipment and propellant as well as OMV propellants, and has an integral airlock that doubles as a storm shelter. Many subsystems associated with the habitat are also located on the service module. The propellant storage system design includes tank modules equipped with quick-disconnects that allow remote modular replacement from an unmanned OTV pallet. The RCS system is designed to operate with or without the habitat module, OMV, and/or the OTV attached.

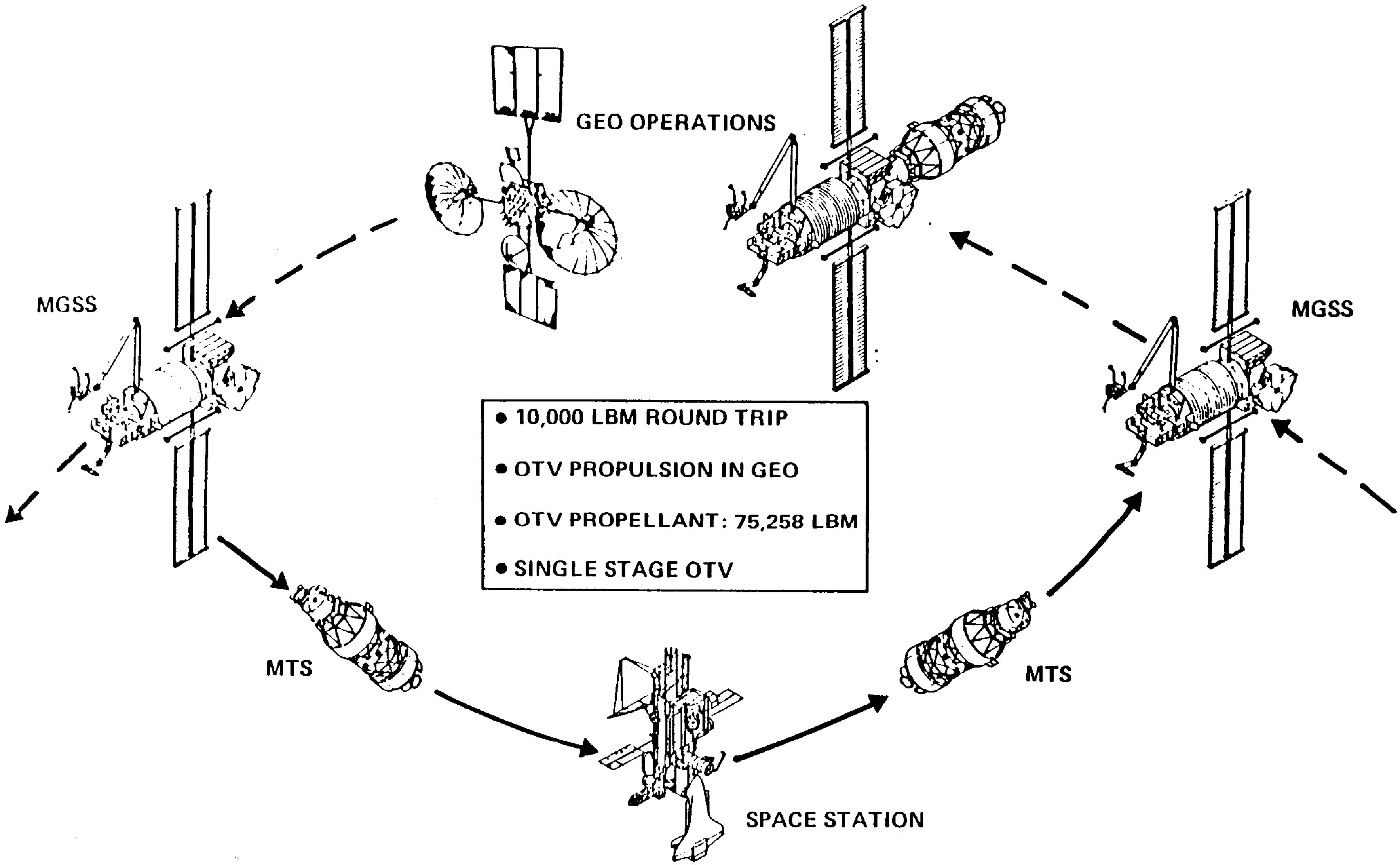

Figure 2.2.2-5 Manned Servicing — GEO-Based Concept

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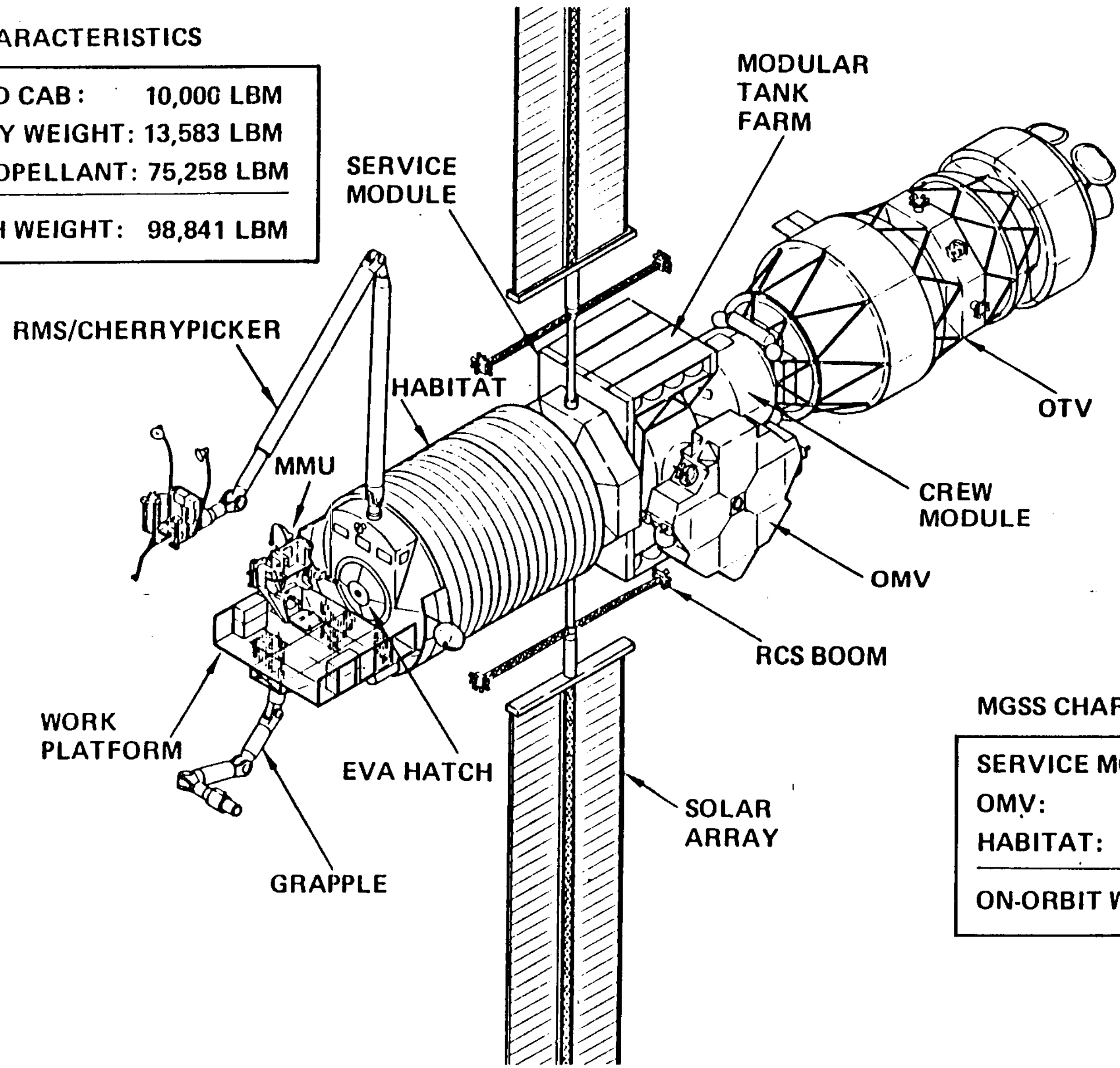
OTV CHARACTERISTICS

MANNED CAB :	10,000 LBM
OTV DRY WEIGHT:	13,583 LBM
OTV PROPELLANT:	75,258 LBM
LAUNCH WEIGHT:	98,841 LBM



MGSS CHARACTERISTICS

SERVICE MODULE:	13,583 LBM
OMV:	4,510 LBM
HABITAT:	17,256 LBM
ON-ORBIT WEIGHT:	35,349 LBM

Figure 2.2.2-6 Manned Mission Configuration — GEO-Based Concept

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The habitat module is a shortened, derivative version of the Space Station common module design, including regenerative life support systems. The workstation attached to it includes a satellite grapple fixture, RMS/cherrypicker, tool storage, and manned maneuvering unit (MMU). Further weight breakdown of the service and habitat modules is presented in section 2.2.2.2.

The LEO-based manned mission approach is shown in figure 2.2.2-7. An OTV with a crew module containing all required life support, GPE, mission equipment and propellants rendezvous with a satellite, services it, and proceeds to subsequent satellites before returning to LEO. Old replacement equipment modules are returned to LEO with the manned cab. The mission profile is the same as for the GEO-based MGSS approach.

The weight data shown reflect a crew module and support equipment weight of 14,400 lb which is consistent with the MGSS estimates, 2000 lb of refueling propellant and 2000 lb for satellite replacement modules (spares). The crew module has an open-loop life support system scaled from STS data. The lower return weight reflects propellants that are off-loaded during servicing.

Because of its weight, the LEO based manned GEO servicing mission is done more efficiently with a two-stage OTV. These stages were assumed to be identical (except for propellant loading) and are individually capable of delivering approximately 20,000 lb to GEO or 7500 lb round trip when fully loaded.

The MOTV crew module, shown in figure 2.2.2-8, is designed for a 15-day mission with an STS-type open loop life support system. Like the MGSS, this cab has a satellite grappler and an RMS. Due to weight limitations, a cherrypicker and MMU are not included. Replacement equipment modules (not shown) are attached to the sides of the crew module.

The crew module design includes provisions for 4 EVA's. A minimum of one EVA per serviced satellite is required because tasks that can be accomplished without EVA can also be accomplished remotely with an unmanned system at considerably lower cost. Simulations of teleoperated control, including transmission-related time delays, show no significant adverse effects.

Cost Analysis

A life cycle cost analysis was conducted to determine the cost relationship between LEO- and GEO-based servicing. The costing data given in this section is based on data available at the OTV midterm review and has not been updated to reflect later developments. However, conclusions drawn from relative cost data would still be valid for the updated groundrules.

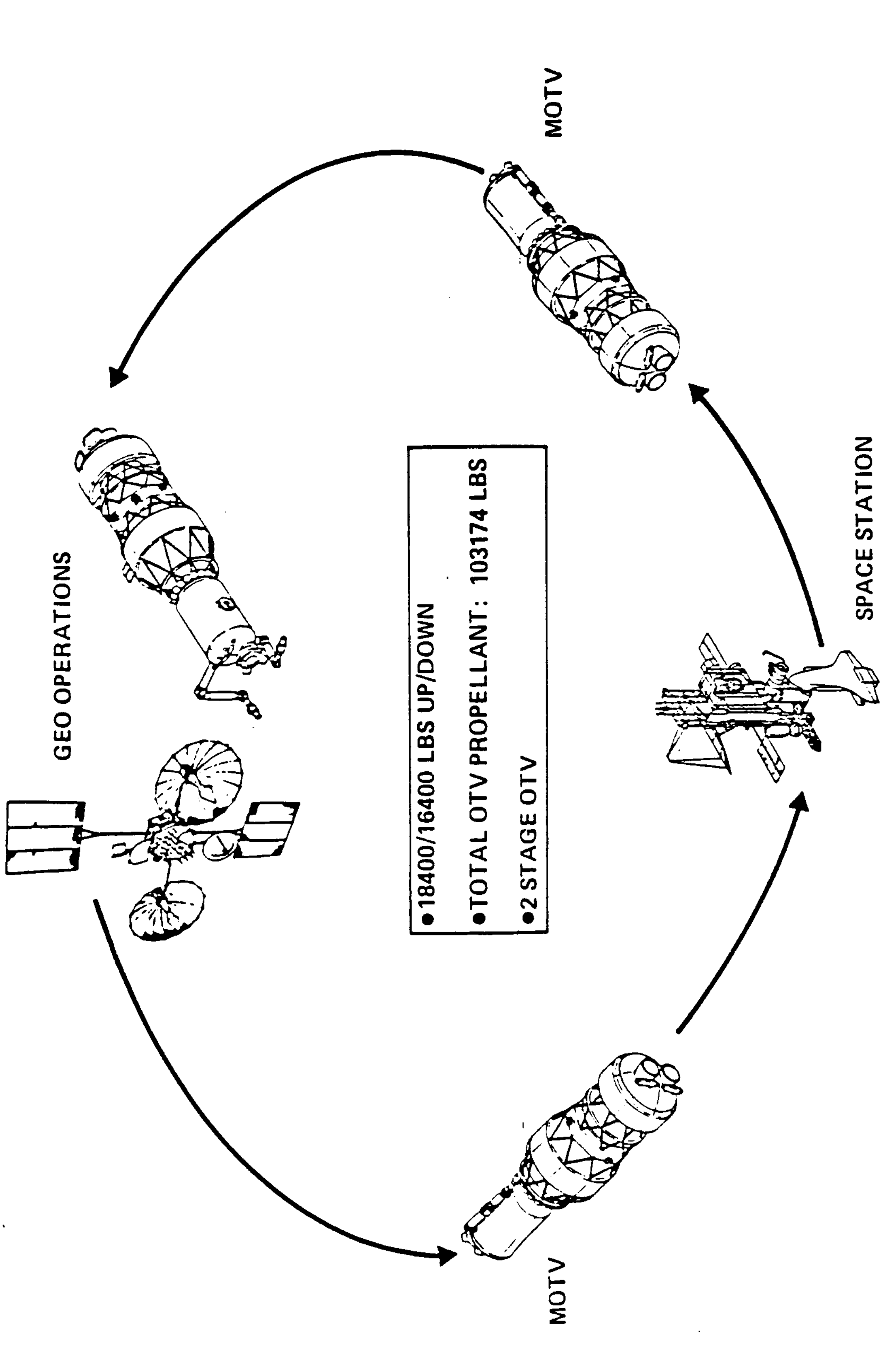

Figure 2.2.2-7. Manned Servicing — LEO-Based Concept

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OTV STAGE 1 CHARACTERISTICS

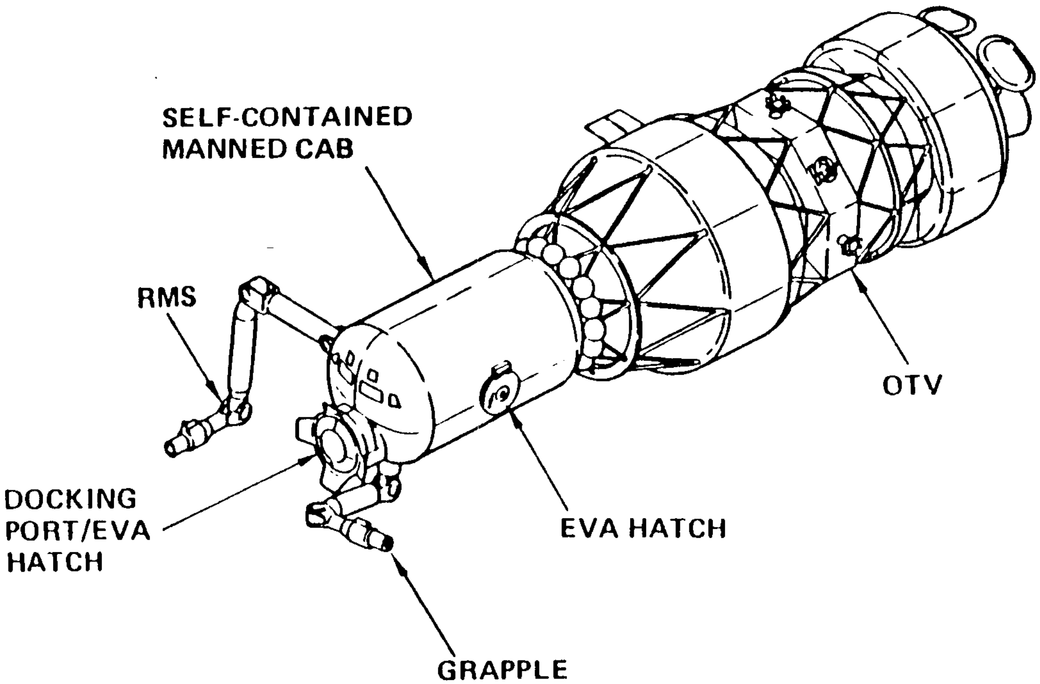
THROW WEIGHT: 87731 LBS
STAGE 1 DRY WEIGHT: 8535 LBS
STAGE 1 PROPELLANT: 43552 LBS

LAUNCH WEIGHT: 139818 LBS

OTV STAGE 2 CHARACTERISTICS

CREW MODULE: 18400 LBS
STAGE 2 DRY WEIGHT: 9709 LBS
STAGE 2 PROPELLANT: 59622 LBS

IGNITION WEIGHT: 87731 LBS



MANNED CAB CHARACTERISTICS

INITIAL WEIGHT: 18400 LBS
END-OF-MISSION WEIGHT: 16400 LBS

Figure 2.2.2-8 Manned Mission Configuration (Self-Contained)

OTV-292

Costing of the servicing missions was accomplished by using the BAC version of the nominal (Rev. 7) model that had 252 OTV flights. This version of the model had been submitted to NASA for approval and was subsequently modified by NASA to form the Rev. 8 model. The analysis considered both LEO- and GEO-based servicing. The results are shown in figure 2.2.2-9. As can be seen, GEO-basing offers substantial undiscounted savings ($8B or 55%) over the duration of the model. Though annual funding levels are higher in the early years when DDT&E is high ($194M vs. $65M), GEO-basing pays for itself in 3 years because of lower operations costs ($107M vs. $380M annual funding) due to less weight being launched.

The costing analysis was further refined by determining the breakdown of the $8B savings of the GEO based approach. The contribution provided by unmanned servicing portion of the model is shown in figure 2.2.2-10. The LEO and GEO based approaches were analyzed using identical mission requirements and OMV performance characteristics. The results indicate a clear life cycle cost advantage ($4.2B) to GEO-based unmanned servicing, despite inclusion of cost scar penalties associated with the manned growth provisions in the MGSS service module. All other manned mission effects were excluded from the cost analysis, therefore the costs shown in figure 2.2.2-10 are for the complete 252 flight model minus the 41 manned missions. Examination of the unmanned servicing dedicated OTV flight rates shows one of the key reasons for the high cost of LEO-based unmanned servicing: only 3 dedicated OTV launches (most servicing deliveries are multiple-manifested) are required for GEO-based servicing versus 54 for LEO-based servicing during the mission model time frame. This results in much higher net delivery costs for LEO-based servicing mass. Not shown on the chart are 10 equivalent OTV flights due to the multiple manifesting. Though multiple manifesting of servicing mass for GEO-based servicing does have costs associated with it, which have been taken into account in the cost analysis, they are significantly lower than dedicated launch costs.

A direct comparison was also made between manned servicing concepts and is shown in figure 2.2.2-11. The two approaches have nearly identical flight schedules; the only differences are the timing of MGSS/GEO Space Station component launches. The life cycle costs of the two approaches are quite different, however, with GEO- based manned servicing (MGSS) performing significantly better ($3.8B). This is explained by the relative sizes of the two manned crew modules: though both fly the same number of missions (41), one uses a single stage OTV (60,000 lbs propellant) and the other uses a two-stage OTV (103,000 lbs propellant). The cost advantage of the lightweight MGSS crew module is somewhat mitigated by discounting of the DDT&E costs for the LEO-

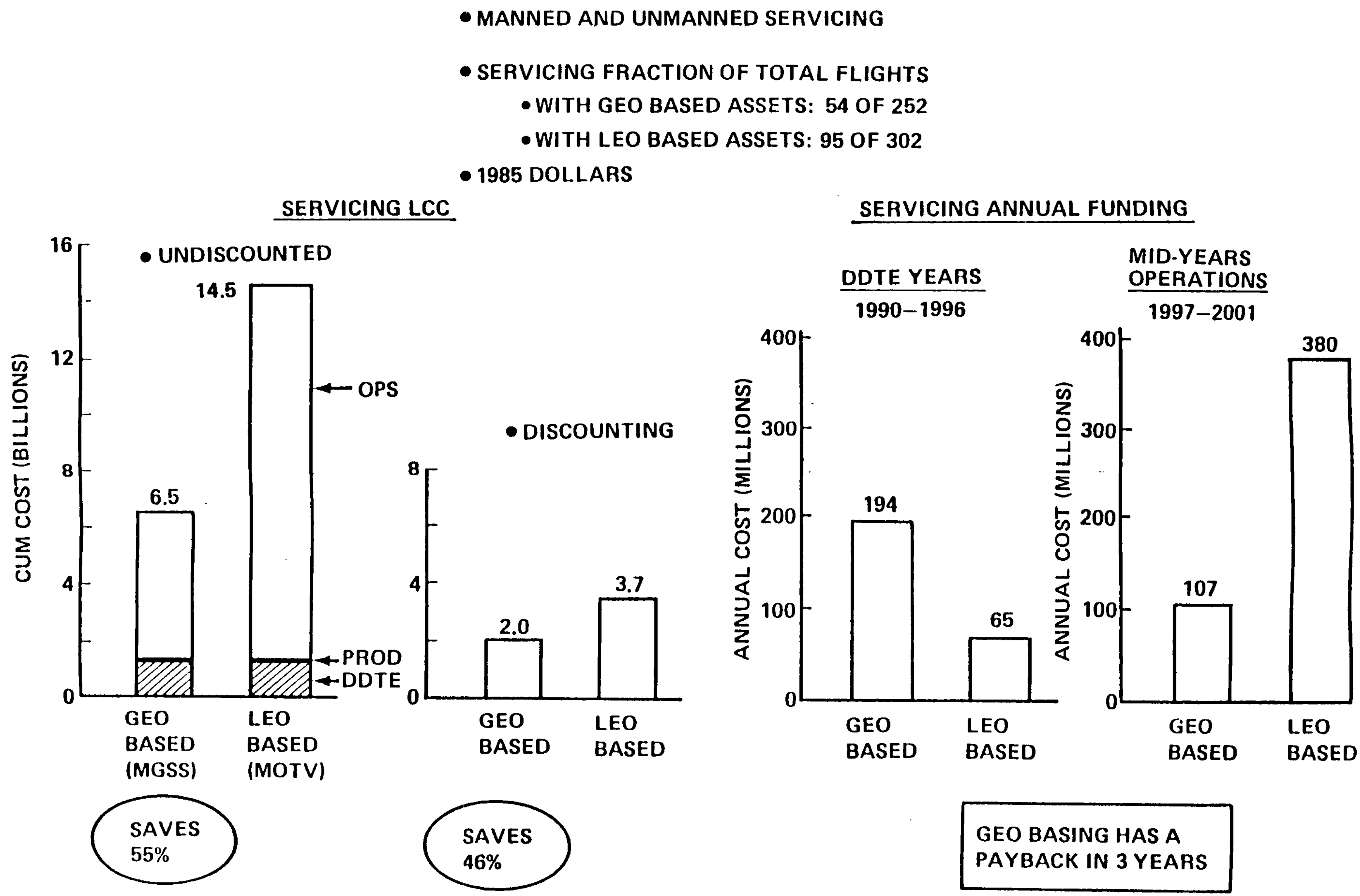


Figure 2.2.2-9 Satellite Servicing Comparison

OTV-207

- NOMINAL BAC MODEL
- 4510 LB OMV USED FOR SERVICING
- OMV SERVICES 4 SATELLITES PER MISSION
- 15-DAY SERVICING PERIOD ($20^o/20^o/20^o/60^o$ PHASE PROFILE)
- PROPELLANT USAGE: 600 LBS (MMH/N_2O_4; GN_2)
- AVERAGE SERVICING MASS: 1700 LBS PER MISSION
- GEO-BASED PROPELLANTS DELIVERED AS SECONDARY PAYLOADS

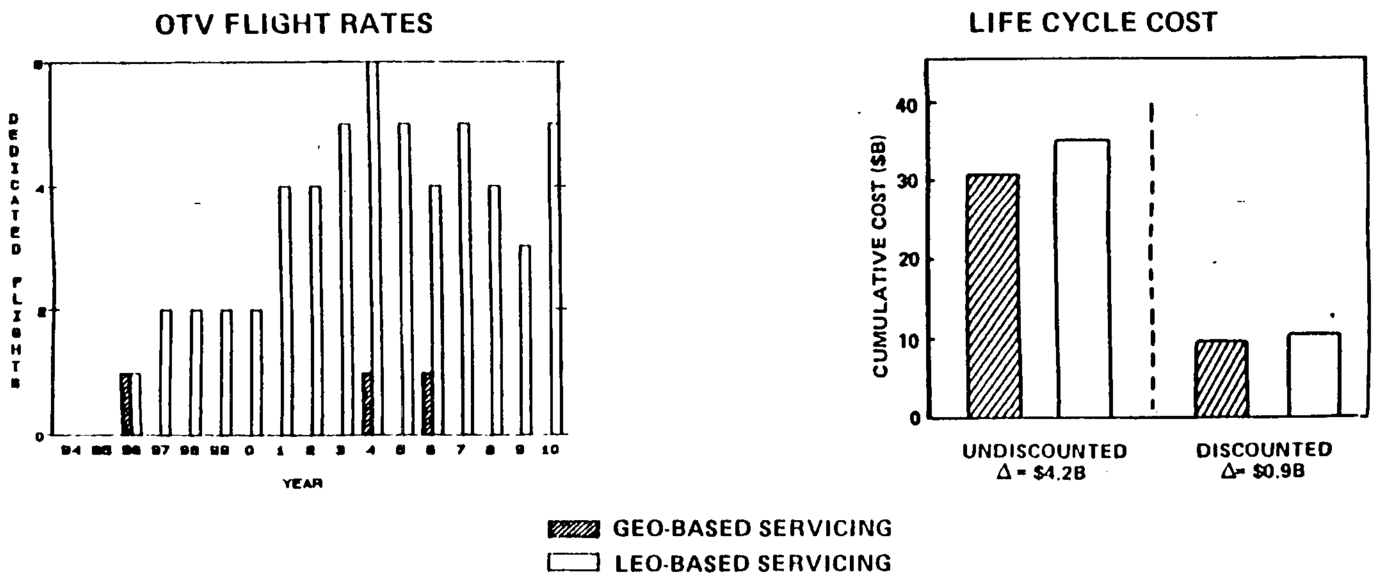


Figure 2.2.2-10 Unmanned Servicing Cost Analysis

OTV-317

- NOMINAL BAC MODEL
- OTV SIZED FOR MGSS MANNED MISSION
- MGSS MISSION: 7500 LBS ROUND TRIP
- SELF-CONTAINED MISSION: 18400/16400 LBS UP/DOWN (2-STAGE OTV)
- BOTH MODELS GROW TO A GEO SPACE STATION (2002)
- GEO SPACE STATION CREW ROTATION: 4 FLIGHTS/YEAR

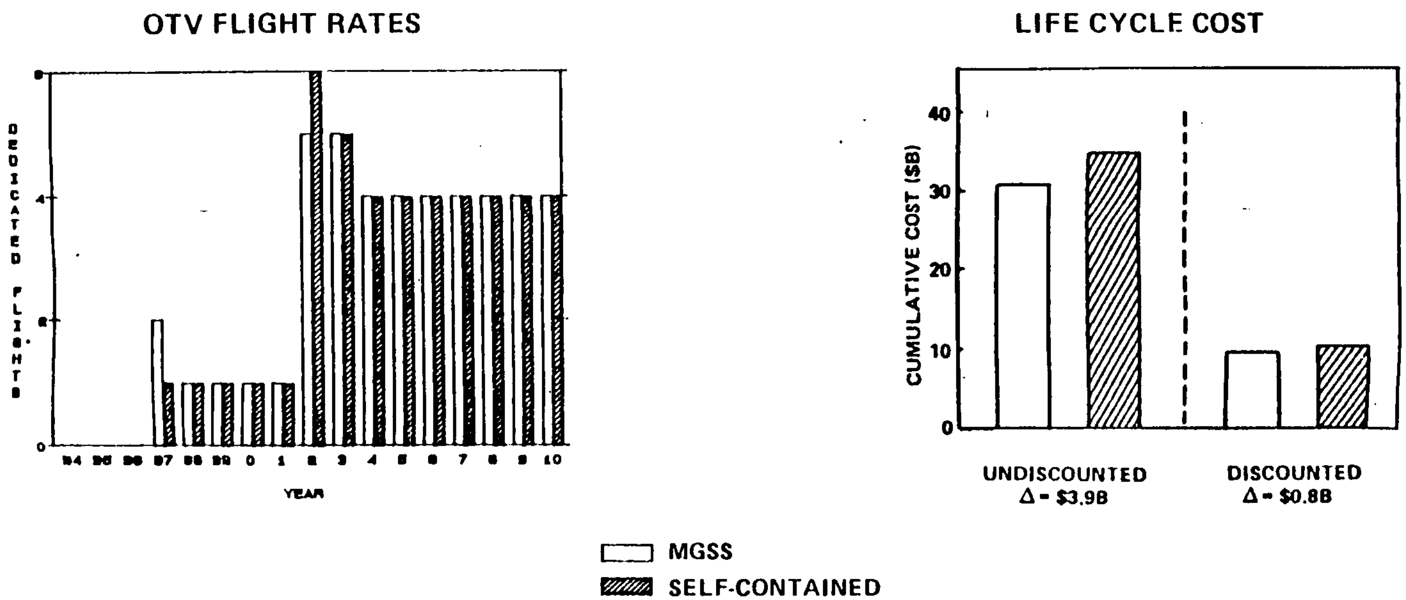


Figure 2.2.2-11 Manned Servicing Cost Analysis

OTV-318

based approach. Though the two approaches have nearly equal DDT&E costs, the LEO-based approach does not introduce GEO habitation elements for five years after the MGSS approach.

Logistics Requirements for Selected Option (GEO Servicing)

Servicing logistics calculations are given in tables 2.2.2-2 and 2.2.2-3 for the BAC low and nominal models. Servicing logistics falls into two categories:

a. Propellant/equipment to be transferred/installed onto serviced satellites.
b. Propellant/supplies required to operate OMV and to support the manned habitat.

The category (a) servicing requirement calculations assumed that given percentages of satellite mass were replaced at regular intervals, depending on technology level of the satellite. The values given for satellite servicing mass are assumed not to include tankage or other packaging allocations. In the mission model multiple manifesting analysis the tankage/packaging allocation was handled by assuming that a fixed inert mass was added to the OTV multiple carrier mass.

The OMV per-mission propellant requirements are based on an average payload delivered to four satellites. The pre-2002 manned logistics requirements assume that all MGSS gases are replaced on each mission. Post-2002 manned logistics assume 90 day expendables resupply (including gas leakage).

It should be noted that while the OTV has a 7500 lb round trip capacity, the manned transfer cab only weights 5700 lb. The additional capacity is used for logistics and mission-peculiar replacement modules.

Summary

Manned mission characteristics discussed earlier are summarized in table 2.2.2-4 for comparison purposes. Principal differences between the two approaches (crew module, weight, equipment, and propellant manifesting) explain the differences in OTV propellant requirements and mission and program costs. The crew module weights shown are those used for the performance analysis. These weights can vary, depending on mission assumptions. For example, a minimum weight LEO based mission would weigh 14,400 lb round trip. This value was not used in the analysis because it does not include the equipment/propellant mass required to perform servicing missions.

In any case, GEO-basing (i.e., MGSS) was found to be the most cost-effective method of achieving GEO servicing objectives (both manned and unmanned). Unmanned servicing missions require the full-time use of an MGSS-based GEO-OMV, but logistics

Table 2.2.2-2. GEO Servicing Requirements (BAC Low Model)

• Mass in K-Lbs

Number of Servicing Missions			Satellite Replacement Mass Req't ①			Support Mass Req't		
Unmanned	Manned	Year	ACS Propellant	Equipment (Unmanned)	Equipment (Manned)	OMV ① Propellant	MGSS ② Logistics	Total Mass Req.
		1996						
		1997						
1		1998	0.5	1		0.6		2.1
		1999	0.6					0.6
1		2000	0.6			0.6		1.2
1	1	2001	1.1	0.5	0.5	0.6	0.9	3.6
1	1	2002	2.3	0.5	0.5	0.6	0.9	4.8
1	1	2003	1.7	0.5	0.5	0.6	0.9	4.2
1	1	2004	2.2	1	1	0.6	0.9	5.7
1	1	2005	1.6	1	1	0.6	0.9	5.1
1	1	2006	2.2	1	1	0.6	0.9	5.7
1	1	2007	2.2	1	1	0.6	0.9	5.7
1	1	2008	2.4	1.8	1.8	0.6	0.9	7.5
1	1	2009	1.6	1	1	0.6	0.9	5.1
1	1	2010	1.7	0.5	0.5	0.6	0.9	4.2

① Does not Include tankage/packaging
② Includes tankage/packaging

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Table 2.2.2-3. GEO Servicing Requirements (1) *(BAC Nominal Model)*

• Mass In K-Lbs

Number of Servicing Missions		Year	Satellite Replacement Mass Req't (1)			Support Mass Req't		Total Mass Req.
Unmanned	Manned		ACS Propellant	Equipment (Unmanned)	Equipment (Manned)	OMV (1) Propellant	MGSS (2) Logistics	
1		1996	1		1	0.6		2.6
2	1	1997	3			1.2	0.9	5.1
2	1	1998	4		1	1.2	0.9	7.1
2	1	1999	3			1.2	0.9	5.1
2	1	2000	3			1.2	0.9	5.1
4	1	2001	5		2	2.4	0.9	10.3
4	4	2002	7		2	2.4	8	19.4
5	4	2003	6	1	2	3	8	20
6	4	2004	9	1	4	3.6	8	25.6
5	4	2005	7	2	4	3	8	24
4	4	2006	8	1	4	2.4	8	23.4
5	4	2007	6	2	3	3	8	22
4	4	2008	7	1	4	2.4	8	22.4
3	4	2009	6	1	4	1.8	8	20.8
5	4	2010	6	2	3	3	8	22

(1) Does not include tankage/packaging
(2) Inclues tankage/packaging

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Table 2.2.2-4 Manned Mission Comparison

- SAME 4 SATELLITES SERVICED BY BOTH APPROACHES

MGSS	SYSTEM PARAMETER	SELF-CONTAINED
7500/7500 LBS U/D	UP/DOWN PAYLOAD	18400/16400 LBS U/D
MGSS	GEO PROPULSION	OTV
LAUNCHED WITH CREW MODULE (2000 LBS)	NEW EQUIPMENT MODULES	LAUNCHED WITH CREW MODULE (2000 LBS)
RETURNED TO LEO ON UNMANNED OTV	OLD EQUIPMENT MODULE	RETURNED TO LEO ON MANNED OTV (2000 LBS)
STORED AT MGSS LAUNCHED ON UNMANNED OTV FLIGHTS	SERVICING FLUIDS	LAUNCHED WITH CREW MODULE (2000 LBS)
60,000 LBS	TYPICAL OTV PROPELLANT LOADING	103,000 LBS
0	DELTA PROGRAM COST	+$3.9B
0	DELTA PER MISSION COST	+$94.5M

OTV-320

requirements to support it are relatively low. In addition, the modular design of the service station provides for a step-by-step buildup that minimizes the impact on the OTV program from a design as well as a budgetary point of view, and provides a firm foundation for growth beyond the initial GEO servicing mission.

2.2.2.2 Mobile GEO Service Station Concept Definition

MGSS Concept

The MGSS concept evolved as a method of eliminating manned GEO servicing as a "tentpole" OTV design mission. When the habitat function is separated from the crew transfer function, a transportation node is established with several positive features. The addition of a mobile transportation node at GEO allows efficient manifesting of OTV's, thus reducing overall costs. Because the OTV will be designed to capture a wide range of payload sizes, it will rarely fly at its maximum design payload weight. The resulting surplus capacity would be wasted unless secondary payloads could be routinely piggy- backed on the OTV for later delivery to the MGSS or elsewhere.

The mobility of the MGSS allows pre-positioning near the primary payload delivery point. After delivery the OMV would be used to retrieve the secondary payload. This approach minimizes the impact of MGSS-directed secondary payloads on the primary mission.

Piggy-backing can present operational problems, especially with high value secondary payloads. This is because the primary mission is more likely to be affected by multiple manifesting when the secondary payload has some level of priority that could affect scheduling or deployment. A general precept of routine multiple manifesting (payload maximization) should be that the secondary payload have low priority, be flexible in size (to accommodate primary payload weight growth), and be easily assembled on short notice (to accommodate unscheduled flights). The most obvious payload for this role is propellant, to be used for OMV propulsion, satellite RCS replenishment and possibly OTV refueling. However, servicing-related equipment can also be manifested on scheduled OTV flights when space is available. This equipment could include replacement equipment modules, hand tools, a manipulator system, space suits, storage facilities, empty fuel tanks, spare parts, food, etc. Some items would be needed for specific planned repair missions (e.g., equipment modules), some are GPE (e.g., hand tools), and others are actually used to expand the MGSS facility (e.g., additional fuel tanks). Over the years the MGSS can be expected to grow many times in size and capability. This growth would be somewhat random in nature, depending on OTV scheduling and mission characteristics.

MGSS Configuration Description. The basic MGSS configuration was shown in figure 2.2.2-6. It has four major system elements: OMV services, service module, habitat/workstation, and manned transfer cab. To minimize development costs, the MGSS uses as much existing hardware and design inheritance as possible. The OMV servicer is a derivative of the LEO OMV design. The other elements borrow from STS and space station designs.

OMV Servicer. The GEO OMV servicer is derived directly from the LEO OMV design. The main differences are the addition of a manipulator system to facilitate unmanned servicing, rechargeable batteries, different propellant tankage, and propellant transfer capability. The GEO OMV is also required to operate longer than the LEO OMV without the benefit of ground servicing, though the service module does allow full power- down of the OMV avionics. This differs from the baseline LEO OMV 90 day hold, which requires that critical components stay turned on.

Though the GEO OMV is based on the LEO OMV design, the GEO operating environment is different from LEO. Specifically, the LEO OMV propellant loading is much too high for GEO operations. The OMV was designed for the retrieval and return of a 25,000 lb satellite through several hundred miles change in altitude. This is a relatively high energy mission. Delta-V requirements at GEO are low for several reasons: 1) satellite retrievals do not involve significant altitude changes, and 2) low energy phasing orbits can be used. Therefore, many of the design assumptions for the LEO OMV do not apply at GEO. The OMV is assumed to weigh 4510 lb based on preliminary design dated from MSFC dated January 1985.

Service Module. The service module previously shown in figure 2.2.2-6 provides most of the MGSS housekeeping functions (power, RCS, avionics), as well as providing habitat environmental control/life support (EC/LSS) equipment, crew airlock/storm shelter, satellite servicing equipment, equipment and propellant storage, and OMV and OTV docking facilities. A summary weight statement is given in table 2.2.2-5.

Habitat Module. The MGSS habitat also shown previously in figure 2.2.2-6 is designed for a four man crew, although its nominal mission is only with two men. The crew systems assume a shuttle level of liveability (14.7 psi shirtsleeve environment)

TABLE 2.2.2-5
MGSS: SERVICE MODULE WEIGHTS

ITEM	WEIGHT		REMARKS
Structure	7341		
Pressure Shell	3493		t=0.68 in. Aluminum
Support Structure		2402	Rings, Fittings, Equip. Struct., Tank Farm
Meteoroid/Debris Shielding		0	TBD
Hatches (4)		496	For Ingress/Egress
Windows			Not applicable
Decks, Storage		50	
Misc., Docking Struct.		900	Docking Mech.
Thermal Protection	76		MCI-40 layer
EC/LSS	585		
Atmosphere Press. System		177	O_2/N_2 Supply-pressurization
Atmosphere Revit. System		120	Ventilation System
Active Thermal Control		288	
Crew Accommodations	216		
Food Management		65	Emergency use only
Water Management		30	Emergency use only
Waste Management		15	Emergency use only
Storage/Sleeping		0	In Habitat Module
EVA Provisions		0	In Habitat Module
Safety/Emergency		76	Fire Suppression, First Aid
Cabin Accommodations		10	Handholds
Misc.		20	
Electrical Power Supply	2300		
Power Supply		1935	Solar Arrays-Deployable (1000 ft^2)
Power Distribution		365	Wire Harness, PDV, Etc.
Avionics, Instrumentation	773		

TABLE 2.2.2-5
MGSS: SERVICE MODULE WEIGHTS
(CONTINUED)

Satellite Servicing Equip.	520		Inc. Computer, Cabling, Umbilical
Structure		370	RCS System Structures
OMV Support		150	Allowance
Tools, Equip. Support		--	
Weight Growth	1772		
(Dry Weight)	(13,583)		
Supply Structure, Inc. Growth		4510	GEO OMV Dry Weight
(Launch Weight)	(18,093)		

with an 18 day nominal mission length. In case of an emergency where the OTV becomes disabled, the MGSS carries a 45-day contingency supply. Emergency supplies are included in the initial habitat deployment and are resupplied as necessary. The habitat systems are also capable of continual operation when manned GEO operations justify a year-round presence.

The habitat provides 2 gm/cm^2 (equivalent Aluminum) radiation shielding for normal conditions. The shielding is provided by the capsule skin, internal equipment, MLI, and meteoroid shielding. Shielded suits must also be worn during normal working conditions. Shielded sleep stations provide shielding during sleep periods. In the event of solar storms the docking module (located in the service module) provides 10 gm/cm^2 proton shielding.

The EC/LSS and water management systems are regenerative. An active purification unit allows water recycling. Oxygen generation equipment is included but nitrogen must be supplied separately. Carbon dioxide is reduced using the Sabatier process.

The habitat gas supply is designed for 4 EVA's plus a contingency for one repressurization event due to cabin atmosphere contamination. Crew egress for EVA is normally done through the airlock at the front of the habitat. Egress is also possible through the OTV docking module port. The life support systems are designed for fail-safe operation. In the event of an OTV failure the habitat is capable of life support until arrival of a rescue mission (45 days). In the event of a life support system failure, the OTV would still be operable, so the mission would be cut short and the crew would return to LEO early.

A summary weight statement is given in table 2.2.2-6. The weights are based on shuttle data (food management, waste management) and IOC Space Station data (structures, EC/LSS, water management).

Crew Module. The crew module used to transfer crew between LEO and the MGSS has a 4 man capability even though it only has a 2 man nominal crew size. This allows rescue of the 2 man MGSS crew in the event of an OTV failure. The crew module configuration is given in figure 2.2.2-12.

The crew module gas supply is sized for a 24 hour nominal mission time plus a 48 hour contingency. The supply also provides for one complete prebreathing event in case of emergency EVA or cabin atmosphere contamination (there are no scheduled EVA's). The cabin has an 8 psi shirtsleeve environment. This is 6.7 psi less than the MGSS cabin pressure (14.7 psi) so the crew must undergo prebreathing before leaving the MGSS

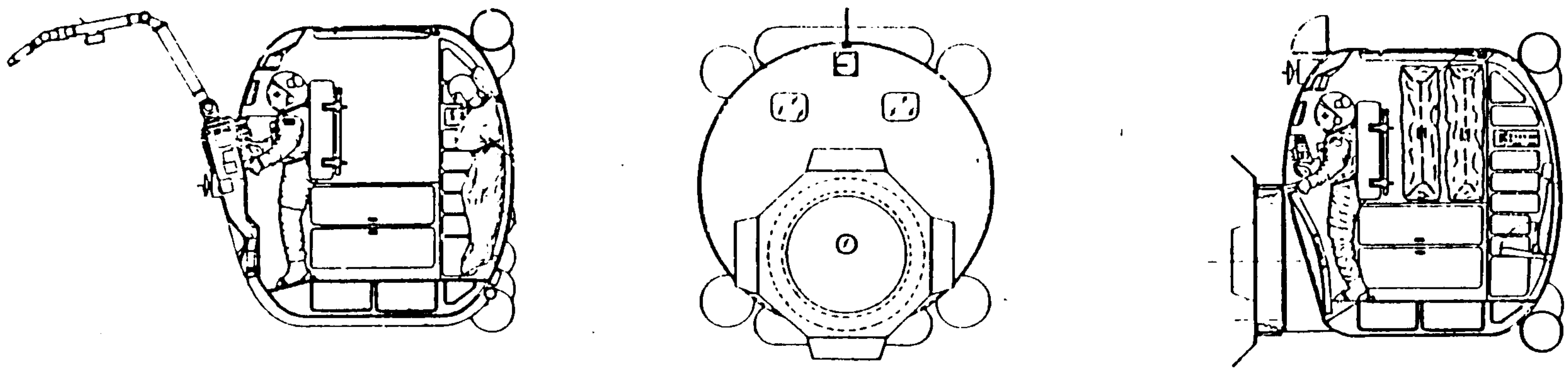
TABLE 2.2.2-6 MGSS: HABITAT MODULE WEIGHTS

ITEM		WEIGHT	REMARKS
Structure	7183		
Pressure Shell		2163	t=0.15 in. 2219 Aluminum
Support Structure		906	Rings, Grapple, Etc.
Meteoroid/Debris Shielding Only		639	t=.03 in. Aluminum Bumper Wall
Hatches (3)		372	
Windows (3)		300	Aluminosilicate Redundant Panes
Decks, Storage		1830	Tilt Racks Storage
Misc., Inc. Docking Struct.		973	Airlock & Docking Mech.
Thermal Protection	165		MLI-40 layer
EC/LSS	2013		
Atmosphere Press. System			438 O_2/N_2 Supply
Atmosphere Revit. System			761 Regenerable CO_2 Removal-Solidamine Unit
Active Thermal Control		814	Water/Freon Coolant Loops
Crew Accommodations	1687		
Food Management		204	Galley Unit & Plumbing
Water Management		554	Water Storage Purification Systems
Waste Management		182	Commode Waste Storage Compactor
Storage/Sleeping		331	Shielded Sleepstations
EVA Provisions		0	Inc. in Crew Module
Safety/Emergency		106	Fire Suppression, First Aid
Cabin Accommodations		250	Work Stations, Shielded Worksuits
Misc.		60	Health/Fitness
Electrical Power Supply	300		
Power Supply		--	Included in Service Module
Thermal Control		--	Included in Service Module

TABLE 2.2.2-6
MGSS: HABITAT MODULE WEIGHTS
(CONTINUED)

Power Distribution		300	
Avionics, Instrumentation	418		Some in Service Module
Satellite Servicing Equip.	3237		
Structure, Inc. RMS		2293	1.0 and 0.5 Scale RMS & Platform
MMU Support		694	
EMU Support		80	
Tools, Equip. Support		170	Boxes, Tools
Weight Growth	2250		
(Dry Weight)	(17,256)		
(Launch Weight)	(17,256)		

- 2 MEN FOR 5 DAYS
- 4 + MAN CAPACITY



STRUCTURE–BODY	2153
THERMAL PROTECTION	53
ENVIRONMENTAL CONTROL/LIFE SUPPORT	576
CREW ACCOMMODATIONS	715
ELECTRICAL POWER	389
AVIONICS, INSTRUMENTATION	657
SATELLITE SERVICING	––
WEIGHT GROWTH	681
(DRY WEIGHT–LBS)	(5221)
CREW	370
CREW EQUIPMENT	––
CONSUMABLES	172
(LAUNCH WEIGHT–LBS)	(5763)

Figure 2.2.2-12. Crew Module Design

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airlock. The crew module has no separate airlock so complete venting of the cabin is required during EVA. The use of hard 8 psi suits (same as cabin pressure) allows rapid evacuation of the crew module without delays due to pressure equalization between the cabin and the suits, as would be the case with the MGSS habitat. Egress from the crew module can occur through either the universal docking hatch or through the EVA hatch.

Included in the crew module design are some redundant OTV components that are required to raise the OTV component redundancy level high enough to meet manned safety requirements (man-rating redundancy kit). The crew module avionics also include communications, monitoring, environmental control, and rendezvous/docking systems not available from OTV. The on-board electrical power system provides power beyond what is available from OTV, although the system redundancy (safety requirement) is provided by OTV backup systems. The OTV itself provides minimal services to the crew module. These services consist of structural, electrical, and data interfaces. The data interface allows monitoring and override of OTV systems control by the crew.

Radiation shielding for the GEO mission is provided by the capsule skin, MLI, debris shielding, and local shielding. The equivalent aluminum thickness is 0.26 inches.

A summary weight statement for the crew module resupply flight is given in table 2.2.2-7 and other satellite supplies delivered by unmanned OTV flights is shown in table 2.2.2-8.

Growth Missions.

Permanently Manned Station. If manned servicing missions exceed four flights per year, it may be desirable to permanently man the GEO work station. This is because the tour of duty is expected to be limited to three months at a time (standard LEO space station crew rotation rate). The cost of maintaining a man on orbit is low compared with the transportation costs, so there is no real penalty after four flights per year. A larger habitat would be required, however.

The establishment of a permanent manned presence in GEO will alter the scope of the MGSS mission. Satellite servicing alone will not be sufficient to occupy the crew's time. This means that other, lower leverage missions could be performed. These could be either civil or military in nature. Growth missions of this type would require that additional hardware be added to the MGSS.

GEO Assembly Platform. Assembly of large space structures does not require a permanent manned presence, but it does require a long duration facility. As such, GEO

TABLE 2.2.2-7

CREW MODULE AND 15-DAY RESUPPLY WEIGHTS

CREW MODULE AND SUPPLIES			COMMENTS
Crew Module)	5221		Equipped for 2-man Transfer
Crew	370		65th Percentile Weight +15 lb Flightsuits
Transfer Consumables	172		O_2, N_2, LiOH Canisters, Food
Resupply Crew Equipment	121		
Hygiene		33	Tissue & Hygiene
Clothing, Etc.		88	30 man-day Supply, Assuming No Clothes Wash
Resupply Consumables	343		
O_2	--		
N_2		138	Assume no N_2 Generator
Water		61	Replace O_2 Leakage (O_2 Generator) and Refill Tank
N_2H_2	0		Delivered on unmanned OTV flight
Food		144	5.2 lb/man-day +50% Packaging
Resupply Tankage, Support (Inc. Growth)	216		
Module Structure		58	Modular Structure for Tank Farm
O_2 Tankage, Plumbing		--	N/A
N_2 Tankage, Plumbing		128	
Water Tankage, Plumbing		20	
Food Containers		10	
Subtotal - Crew Module	(6443)		
Satellite ORU's	(1057)		
Total Weight	7500 lb		

TABLE 2.2.2-8

OTHER SUPPLIES FOR SATELLITE SERVICING

SATELLITE SUPPLIES			COMMENTS
Sat. Refuel Propellants	5104		6-Month Resupply
N_2H_4		3400	
N_2O_4		756	
MMH		344	
GN_2		604	
Propellant Tankage, and Support	1185		
Module Structure		173	Modular Structure For Tank Farm
N_2H_2 Tankage, Plumbing		357	
N_2O_4 Tankage, Plumbing		60	
MMH Tankage Plumbing		40	
GN_2 Tankage, Plumbing		555	
(Subtotal)	(6289)		Delivered on unmanned OTV flights

assembly may be the critical mission that provides the MGSS with a habitat large enough for growth to a permanent manned station. Some of the equipment needed for space assembly (e.g., manipulators, hand tools) can be inherited from earlier servicing missions. Additional support structure and assembly and test equipment will be required.

Manned Lunar/Planetary Missions. The MGSS design approach, wherein the habitat and GPE functions are separated from the crew module function, is applicable to lunar and possibly even planetary missions. Operational experience gained from the MGSS program, as well as technology and component development, may be used to lower the technical risk inherent to these complex missions. For example, long design life subsystems (e.g., habitats) are more applicable to lunar or planetary missions than the short single-shot GEO servicing missions presently envisioned. Finally, the establishment of a transportation node at a libration point or in lunar orbit could significantly enhance the effectiveness of lunar missions, as was the case with GEO missions.

2.2.3 Lunar Program

A variety of lunar mission approaches were investigated during the mission analysis task. The reference approach in the NASA Revision 7 mission model was based on the JSC Lunar Surface Return study. A second more cost-effective lunar mission approach was then developed to meet JSC-LSR mission objectives with fewer impacts on the OTV system. In addition, other lunar transfer concepts, such as Trans Lunar Rendezvous (TLR), proposed by Dr. Buzz Aldrin, were analyzed to determine whether further improvements could be made to the JSC-LSR approach. The analysis showed that the TLR approaches did not have sufficient benefits to justify their use.

The characteristics of the three lunar mission approaches are summarized in table 2.2.3-1. More detailed descriptions of the analysis is given in the following sections.

2.2.3.1 Reference Lunar Program

The reference NASA Revision 7 lunar mission model is given in table 2.2.3-2. A detailed description of the reference mission elements can be found in the NASA-JSC Lunar Surface Return report (March 1984). As will be described in the following section, both the NASA reference and revised Boeing lunar mission approaches accomplish the same mission objectives. Only the implementation method, and the transportation elements in particular, have been changed.

2.2.3.2 Revised Lunar Program

The Boeing lunar mission model is based on the NASA Lunar Surface Return study (March 1984) and the NASA Revision 7 OTV mission model. The LSR study was used to determine overall mission objectives and for descriptions of individual elements of the launch manifest. The Revision 7 model was used to establish launch dates of lunar mission elements.

The lunar mission is a non-funded program with an uncertain start date and should not be allowed to significantly affect the OTV design, though compatibility is desirable. The lunar mission approach taken in this study attempts to meet all mission objectives as described in the LSR study with minimum impacts on OTV performance requirements. It accomplishes this without introducing any new hardware elements into the mission, though some elements (Lunar Service Station) are introduced at earlier dates and others (expendable lunar lander) are eliminated altogether. The model also attempts to show a clear evolutionary path for manned missions, with the lunar mission using design heritage and some hardware elements from manned GEO servicing missions.

Table 2.2.3-1 Candidate Lunar Mission Concepts

NASA LSR STUDY	BOEING OTV MODEL	TRANS LUNAR RENDEZVOUS [1]
• NO PREDEPLOYED MISSION ELEMENTS	• LUNAR SERVICE STATIONS (LSS) IN LUNAR ORBIT	• LUNAR TRANSFER STATION (LTS) IN LUNAR TRANSFER ORBIT
• OTV MANNED CAPSULE/HABITAT SIZED FOR FULL MISSION TIME	• OTV MANNED CAPSULE/HABITAT SIZED FOR CIS-LUNAR TRANSFER TIME	• OTV CREW MODULE SIZED FOR LEO RENDEZVOUS WITH LUNAR TRANSFER STATIONS (LTS)
	• LSS HABITAT SIZED FOR LONG DURATION MISSIONS	• LTS HABITAT SIZED FOR LONG DURATION MISSIONS
• LUNAR MISSION PAYLOADS AND EQUIPMENT MANIFESTED ON SINGLE OTV FLIGHT	• LUNAR MISSION PAYLOADS AND EQUIPMENT MANIFESTED ON MULTIPLE OTV FLIGHTS	• LUNAR MISSION PAYLOADS AND EQUIPMENT MANIFESTED ON MULTIPLE OTV FLIGHTS
• NO MGSS EVOLUTION	• MGSS HARDWARE EVOLUTION	• MGSS HARDWARE EVOLUTION
• NO RESTRICTIONS ON LUNAR ORBIT STAY TIME	• NO RESTRICTIONS ON LUNAR ORBIT STAY TIME	• DEPARTING VEHICLE MUST RENDEZVOUS WITH LTS
• NO RESTRICTIONS ON MISSION LAUNCH DATES	• NO RESTRICTIONS ON MISSION LAUNCH DATES	• LAUNCH WINDOWS OCCUR APPROXIMATELY ONCE PER LUNAR PERIOD
	• RENDEZVOUS WITH LSS	• LTS IN UNSTABLE ORBIT REQUIRING CORRECTIONS EACH ORBIT
		• LTS SUBJECT TO FREQUENT EXPOSURE TO VAN ALLEN BELTS
• PLANE CHANGE DURING LUNAR TRANSFER	• PLANE CHANGE DURING LUNAR TRANSFER	
• MISSION APPROACH REQUIRES OVERSIZED OTV AND LONG DURATION HABITAT	• NOT OTV DESIGN DRIVER BUT REQUIRES CREW MODULE FOR LUNAR TRANSFER	• NOT OTV DESIGN DRIVER WITH LIGHTWEIGHT CREW MODULE, BUT OPERATIONALLY DIFFICULT DURING EARLY LUNAR MISSION PHASES

[1] THE BAC CONCEPT FOR TLR

OTV-1808

Table 2.2.3-2 OTV Mission Model Construction – Lunar Base Program Scenario

MISSION MODEL: NOMINAL

DATE: 5–9–84

REVISION NO.: 7 (SS)

MISSIONS	PLD NO.	MISSIONS/FY																		
		93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	TOT
COMMUNICATIONS RELAY	17200									1										1
GEOCHEMICAL MAPPER	17201										1									1
SURFACE EXPLORER	17202											1								1
MANNED SORTIE	17203														1	1	1			3
BASE ELEMENT DEL.	17204																2	1		3
BASE SORTIE/LOGISTICS	17206																	2	4	6

OTV-1809

The LSR mission is divided into three phases. Phase I involves site selection for a moon base and is completely unmanned. Phase II involves early manned sorties before the moon base becomes operational. Phase III involves manned missions after the moon base becomes operational.

Some major new OTV hardware is required for the manned missions: (1) a tanker design is required for propellant delivery to the reusable lunar lander; (2) a long duration manned transfer habitation module is required because the MGSS crew module is designed for transfer times much shorter than lunar transfers. The habitation module would supplement the crew module.

A comparison of the NASA and Boeing models is shown in table 2.2.3-3. Major differences are replacement of the expendable lander with a reusable OTV-derivative lander, early introduction of the Lunar Service Station, and the use of larger habitation modules for the lunar base, which is made possible by the higher performance of the reusable lander.

Note that delivery requirements as stated for the Boeing model reflect the approximate performance of an OTV with Wp = 55,000 lb. These requirements could be reduced if necessary since they exceed the reference requirements.

The flight manifest for the Boeing low and high models is given in tables 2.2.3-4 and 2.2.3-5. The manifests include hardware deliveries, manned sorties, and propellant tanker deliveries.

Program Description

The establishment of a transportation node in lunar orbit (similar to MGSS) allows integration of lunar surface payloads in lunar orbit. This means that the individual elements can be delivered separately on different OTV flights, thus reducing the performance requirements for each individual OTV mission. A Lunar Service Station is included in the NASA-JSC Lunar Surface Return study. Its two primary missions are to provide an orbiting habitat for manned lunar missions, and to provide facilities for the storage and transfer to OTV of lunar oxygen.

In the proposed changes to the NASA reference mission the LSS would be introduced at an earlier date. Its propellant storage and transfer function would remain, but would initially be oriented toward refueling a reusable lunar lander. The lunar lander is seen as an OTV derivative with retractable landing gear. The LSS would also serve as a transportation node where a manned crew would integrate lunar surface payloads with the lunar lander.

Table 2.2.3-3 Lunar Model Comparison

	JSC LSTC Study	Boeing
Communications Relay Geochemical mapper	5000 lb spacecraft, dedicated launch 5000 lb spacecraft, dedicated launch	} 2 5000 lb. spacecraft, double manifest
Surface Explorer	20,000 lbs. to lunar orbit with integral expendable descent stage	20,000 lbs to lunar orbit with integral expendable descent stage
Lunar Service Station	Man-tended orbiting habitat with storage and handling of lunar-derived oxygen. IOC = 2010 +	Man-tended orbiting habitat with storage and handling of earth or lunar-derived oxygen. IOC = 2005
Phase II Lunar Lander	Expendable storable propellant 15,000 lb OTV manned capsule 38,600 lb delivery (unmanned)	Reusable cryogenic propellant 5000 lbs dedicated crew module 55,000 lbs delivery* plus 5000 lb. capsule
Lunar Base Habitation Modules	36,200 lbs, 3847 ft³, 168" x 352"	51,200 lbs, 6105 ft³, 168" x 528"
Operations	OTV-lander-crew module integration at space station Lander - OTV redezvous and dock in lunar orbit Lander propellant loading at space station	OTV-crew module integration at space station. Lander-crew module integration at space station but crew must transfer from OTV at LSS. Lander-LSS rendezvous and dock in lunar orbit. OTV tanker propellant delivery to LSS Lander propellant loading at LSS (except 1st mission
OTV Performance	80,000 lbs delivery to lunar orbit and 15,000 lbs return	55,000 lbs delivery* to lunar orbit and 12,500 lbs return

* Note: OTV lunar orbit delivery requirement (55,000 lbs.. propellant) can be reduced if lander payload (55,000 lbs) is reduced.

OTV-1833

Table 2.2.3-4 Lunar Mission Model (Boeing-Low)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
LUNAR COMMUNICATIONS RELAY			1								
LUNAR GEOCHEMICAL MAPPER			1								
LUNAR SURFACE EXPLORER					1						
LUNAR SERVICE STATION (LSS)							1				
MANNED SORTIE TO LUNAR ORBIT [1]							1				
LUNAR LANDER DELIVERY TO LSS								1			
MANNED SORTIE TO LUNAR SURFACE [1]								1	1	1	
LUNAR BASE ELEMENTS [1]										2	1
LUNAR BASE LOGISTICS [1]											2
PROPELLANT TANKER [2]								1		3	2

[1] MANNED MISSION

[2] ASSUMES 55 KLB TANKER FOR LUNAR LANDER REFUELING

OTV-1029

Table 2.2.3-5 Lunar Mission Model (Boeing-Nominal)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
LUNAR COMMUNICATIONS RELAY		1									
LUNAR GEOCHEMICAL MAPPER		1									
LUNAR SURFACE EXPLORER				1							
LUNAR SERVICE STATION (LSS)						1					
MANNED SORTIE TO LUNAR ORBIT 1						1					
LUNAR LANDER DELIVERY TO LSS							1				
MANNED SORTIE TO LUNAR SURFACE 1							1	1	1		
LUNAR BASE ELEMENTS 1									2	1	
LUNAR BASE LOGISTICS 1										2	4
PROPELLANT TANKER 2							1		3	2	3

1 MANNED MISSION

2 ASSUMES 55 KLB TANKER FOR LUNAR LANDER REFUELING

OTV-1028

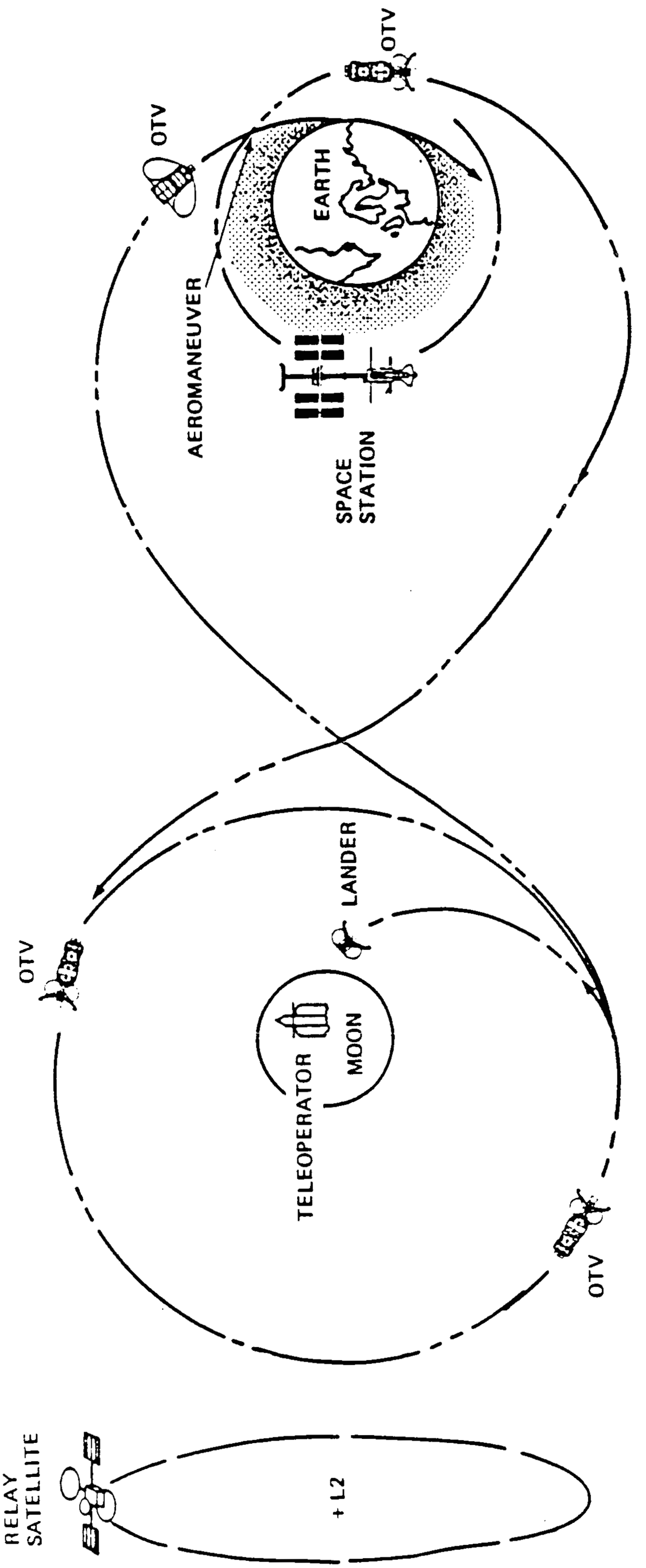
The lunar mission phase I operations shown in figure 2.2.3-1 involve the collection of data on lunar characteristics to aid in the selection of future landing sites. This is accomplished with the use of a Lunar Geochemical Mapper spacecraft, weighing approximately 5,000 lbs and placed in lunar polar orbit. A Lunar Communications Relay spacecraft, weighing approximately 5000 lbs, is deployed on the same OTV mission as the Geochemical Mapper, but is placed into a halo orbit around the L-2 libration point. The Relay spacecraft allows communications with the far side of the moon. It provides enhanced control of the Geochemical Mapper and, subsequently, continuous communications with the manned mission.

A Lunar Surface Explorer vehicle is deployed a few years later to make direct measurements of lunar soil characteristics. Because the LSS has not yet been deployed, the Surface Explorer uses an expendable descent stage. Preliminary sizing (based on Apollo data) gives a pump-fed storable propellant expendable lander weighing 13,000 lbs and capable of delivering 6000 to 7000 lbs to the lunar surface. This mission is within the performance envelope of the OTV. The development of an expendable storable propellant lunar descent stage may not be cost effective, in which case an expendable OTV derivative system could be used.

The lunar mission phase II/III operations are shown in figure 2.2.3-2. In phase II a Lunar Service Station (LSS) is placed in low lunar orbit and serves as a transportation node for all future lunar missions. It is sized for maximum OTV delivery capacity and is derived from the MGSS design. A manned mission using a large crew module weighing 12,500 lbs and consisting of an MGSS crew module with an attached habitat module, is conducted to demonstrate the LSS functions and to perform some tasks (e.g., checkout, alignment, minor assembly) associated with bringing the LSS to full operational status. This mission is followed later by delivery of a reusable lunar lander (partially fueled) with attached manned lunar crew module and the equipment for the first lunar surface mission.

Two additional manned sorties are conducted to the lunar surface to prepare a site for the lunar base. Some propellant delivery flights are also required to support these sorties. The lunar return program does not really begin to build up until the lunar base construction phase (phase III), when large habitat modules and associated ground equipment are delivered to the surface and OTV usage increases to 10 flights a year.

When lunar surface landings begin, a minimum fleet size of three OTV stages is required by the lunar mission: one OTV for the manned sortie and a two stage OTV to deliver lunar payloads or for propellant delivery to fuel the lunar lander. The payload



OTV-1810

Figure 2.2.3-1 Lunar Mission: Phase I (Unmanned)

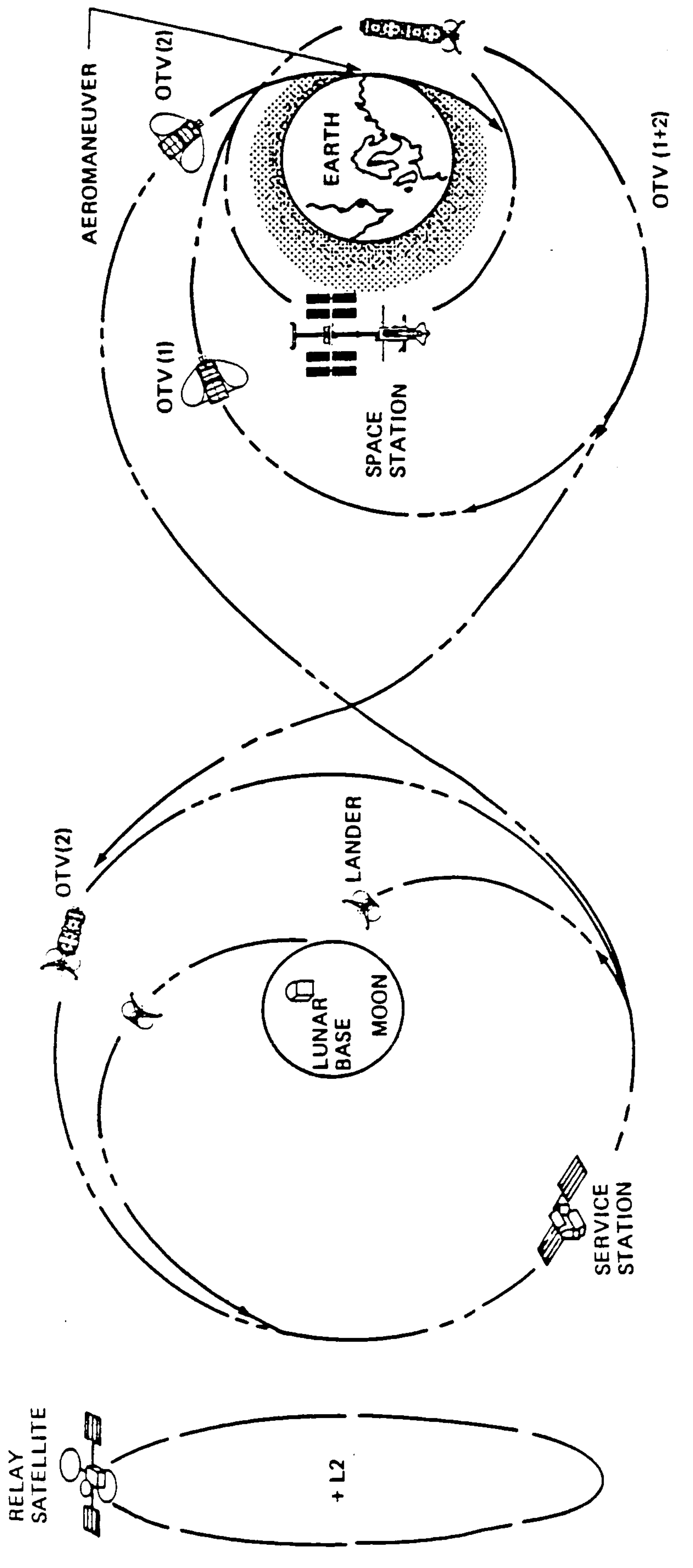


Figure 2.2.3-2 Lunar Mission: Phase II/III

OTV-1811

delivery (e.g., lunar base modules) and the propellant delivery missions can be conducted in series so only two OTV vehicles are needed.

Three basic OTV configurations shown in figure 2.2.3-3 are required for the lunar mission. The unmanned one-stage configuration is used for all phase I and some phase II missions. It closely resembles the GEO delivery configuration though its EPS system must be sized for longer mission times and its aerobrake must be sized for higher reentry velocities.

The manned OTV configuration resembles the manned GEO OTV except for the EPS, aerobrake, and the addition of a habitation module required for the long lunar transfer times. The unmanned two-stage OTV configuration is used for large payload lunar deliveries. It has two identical stages that resemble the GEO OTV except for EPS and aerobrake. To maximize performance, both stages are full at launch. Because of the non-optimal stage size mix, the second stage is required to do part of the perigee burns.

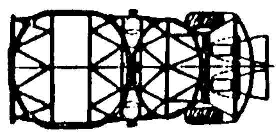
Lunar mission delta-V's, shown in figure 2.2.3-4, depend on the desired mission transfer time. Manned missions require shorter transfer times than unmanned delivery flights because habitat size and mass are mission time dependent. Unmanned delivery flights are longer to minimize delta-V requirements and maximize payload.

The LSS configuration, shown in figure 2.2.3-5, is based on the MGSS design. It has a manned habitat, a service module, docking facilities for both OTV's and lunar landers, payload handling equipment, and propellant storage and transfer equipment. A detailed point design of the LSS has not yet been conducted so the concept shown is only representative of a potential configuration. Unlike the MGSS, the LSS does not require satellite servicing equipment or a remote teleoperator. However, it does require tankage for storage of large quantities of propellant.

Major lunar lander subsystems are derived from the OTV design except for the landing gear. The lunar lander shown in figure 2.2.3-6 is a four tank configuration. It has a low c.g. and appears to be the most attractive OTV derivative. The crew module is not shown. The lander requires 21,400 lbs of propellant for surface sorties, 30,000 lbs for logistics missions, and 55,000 lbs for base element deliveries.

The lunar lander shown in figure 2.2.3-7 is derived from a Shuttle Cargo Bay (SCB) OTV. To lower the c.g. the OTV H_2 tank was divided into two separate tanks. Though this will work as a lander it must be space-assembled because its dimensions exceed both the SCB and the ACC. The crew module is not shown.

Habitat module sizing is given in figure 2.2.3-8. The habitat modules assumed in the JSC LSR study are 29 feet long (3 segment) modules derived from space station



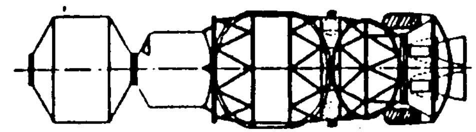
UNMANNED

1-STAGE

55,000 LBS. H_2-O_2

25,000 + LBS DELIVERY TO LUNAR ORBIT FROM EARTH SPACE STATION

AEROBRAKE RETURN



MANNED

1-STAGE

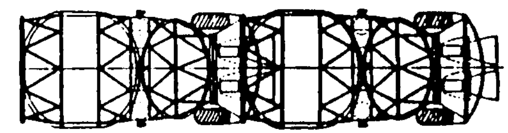
55,000 LBS H_2-O_2

12,500 LBS ROUND TRIP TO LUNAR ORBIT FROM EARTH SPACE STATION

MGSS CREW MODULE

LONG TRANSFER HABITATION MODULE

AEROBRAKE RETURN



UNMANNED

2-STAGE (IDENTICAL)

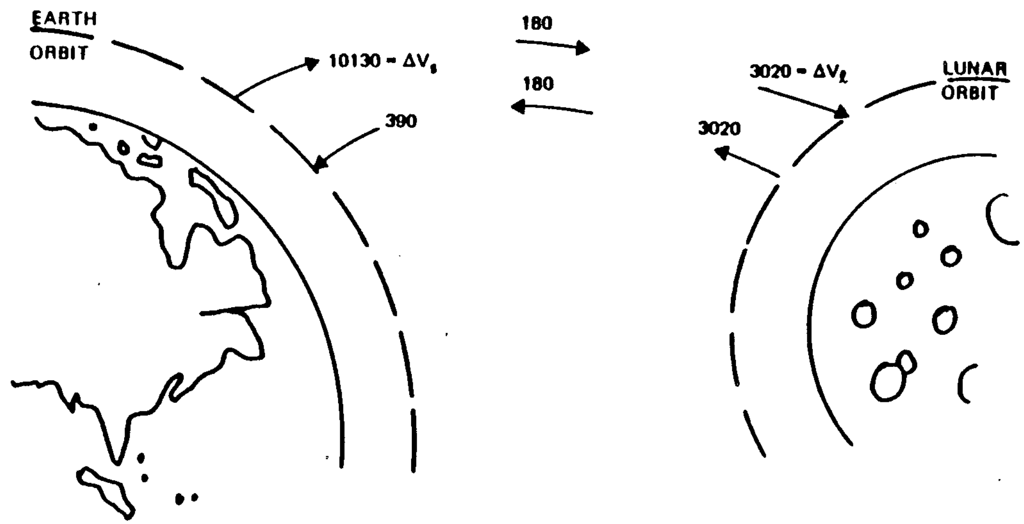
110,000 LBS H_2-O_2

55,000 LBS DELIVERY TO LUNAR ORBIT FROM EARTH SPACE STATION

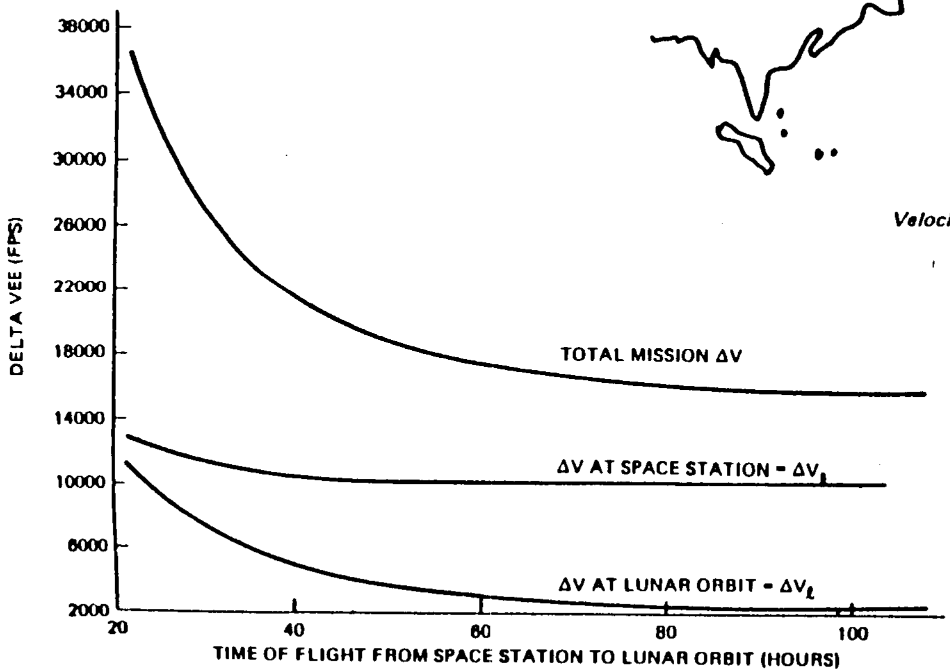
AEROBRAKE RETURN (BOTH STAGES)

Figure 2.2.3-3 OTV Configurations

OTV-1812



Velocity Increments (ft/s) for a 66-hours Mission to Lunar Orbit



Delta Vees from the Space Station to Lunar Orbit

Figure 2.2.3-4 Lunar Mission ΔV Requirements

OTV-1813

OTV-1788

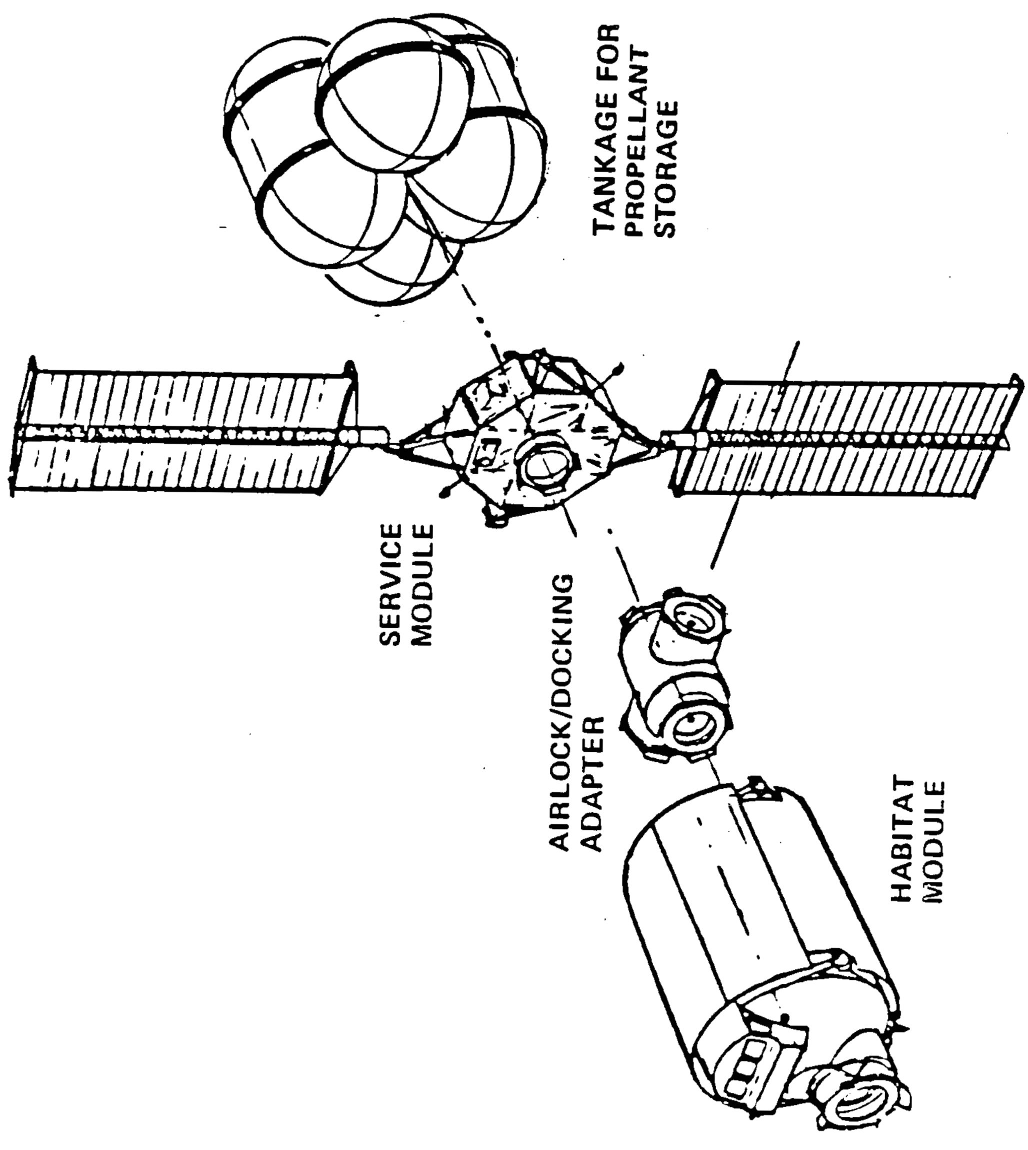


Figure 2.2.3-5 Lunar Service Station Configuration

OTV-1789

- ACC OTV DERIVATIVE
- 55 KLBS H_2–O_2 PROPELLANT

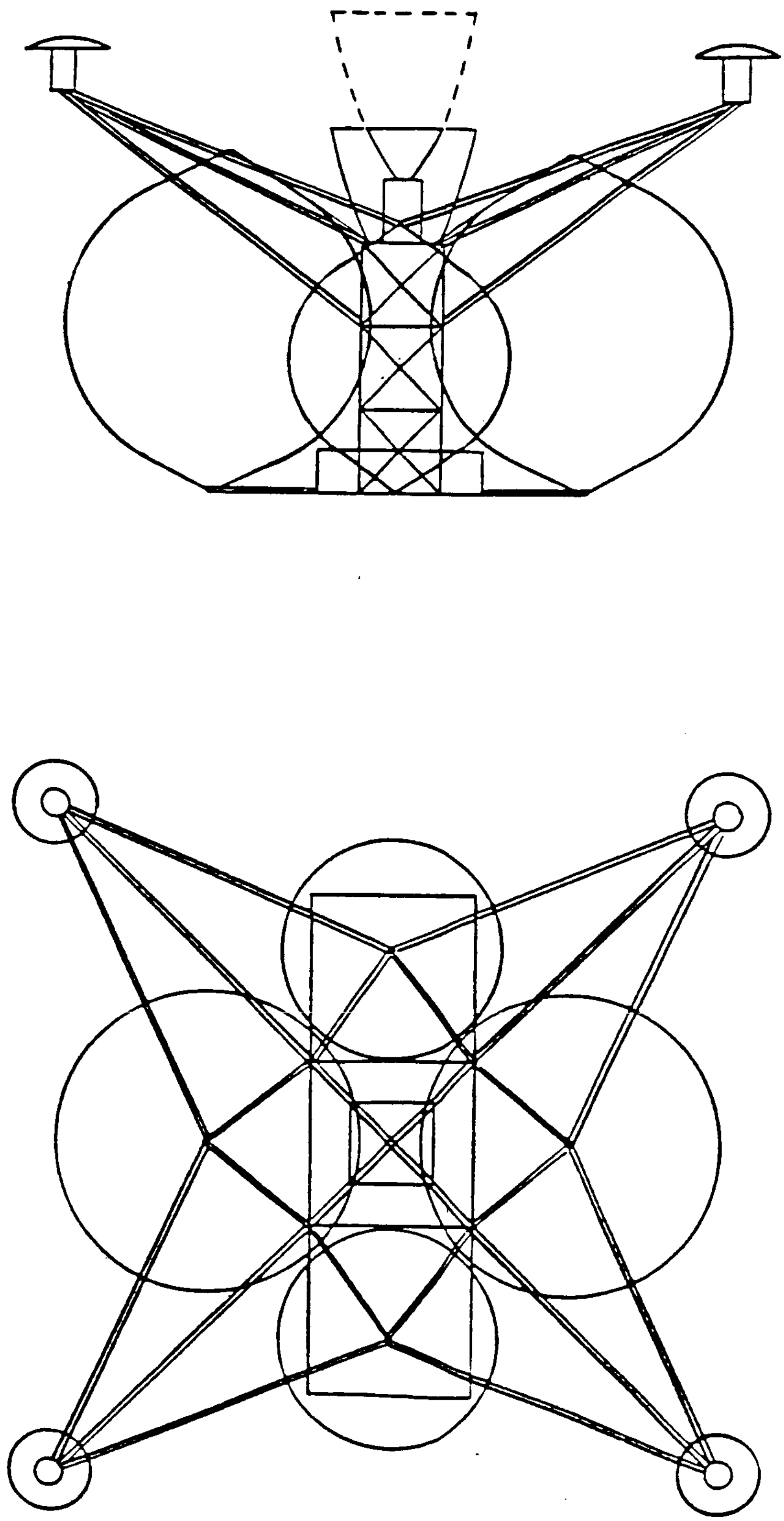


Figure 2.2.3-6 Reusable Lunar Lander

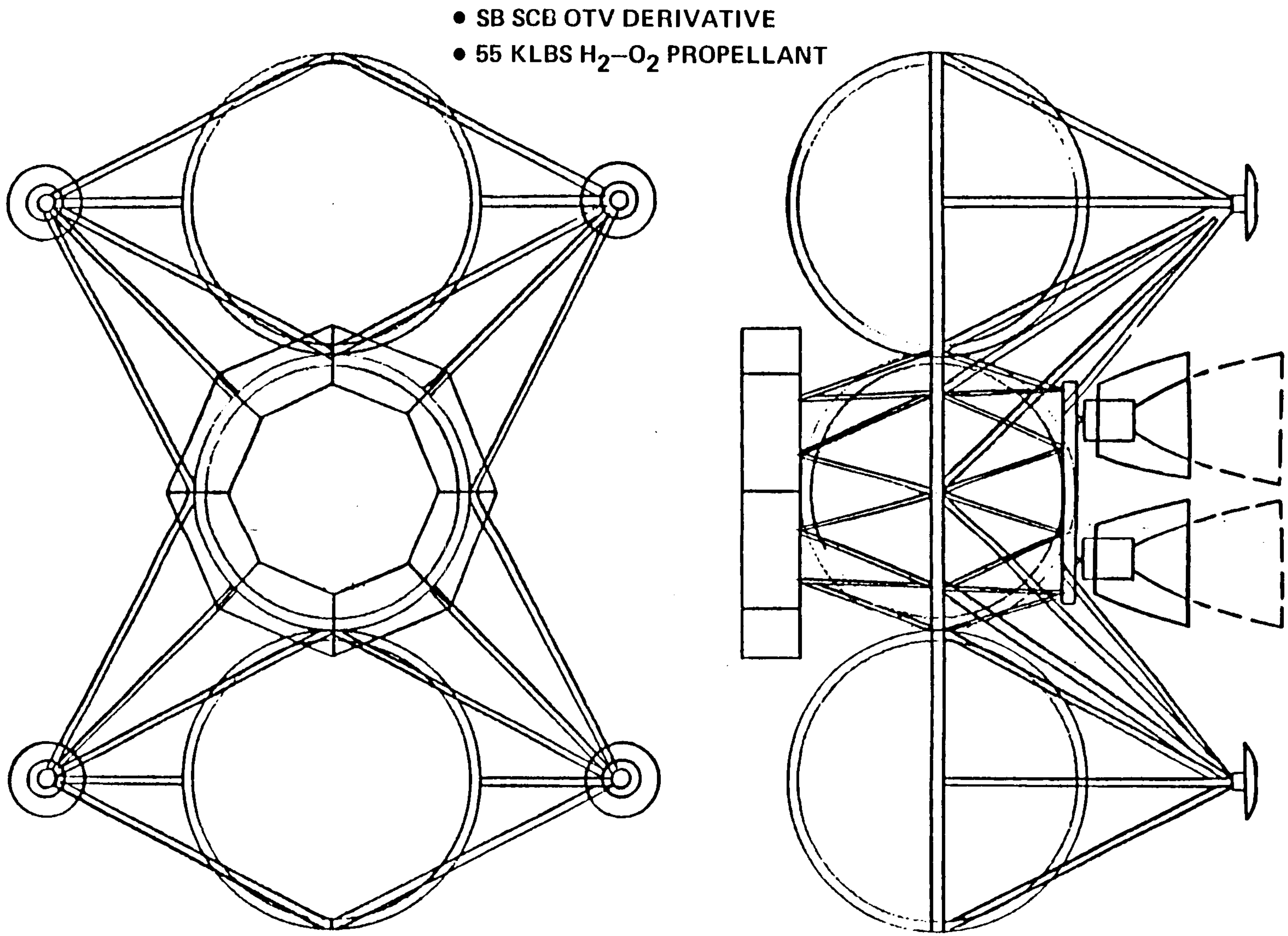
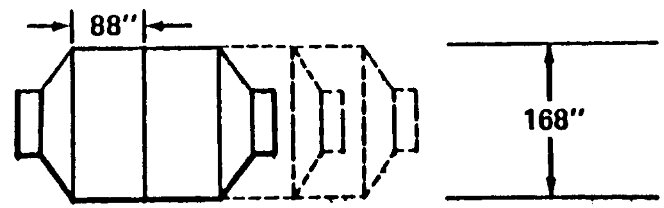


Figure 2.2.3-7 Reusable Lunar Lander

ASSUME 88" SEGMENTS
PER JSC LSR STUDY



NO. OF SEGMENTS	VOLUME, FT3	GROSS WT., LB (AVG)	GROSS WT., LB (HIGH)
2	2718	27,900	34,900
3	3847	36,200	45,300
4	4976	43,900	54,900
5	6105	51,200	64,000

- IF OTV PAYLOAD IS 38,600 LB, THREE-SEGMENT MODULES ARE MAXIMUM USABLE SIZE
- IF OTV PAYLOAD IS 55,000 LBS, FIVE-SEGMENT MODULES ARE MAXIMUM USABLE SIZE
- IF MODULES ARE APPRECIABLY HEAVIER THAN AVERAGE CURVE (E.G., FOR STRUCTURAL BEEF-UP TO RESIST REGOLITH–BURIAL LOADS), THE NUMBER OF MODULE SEGMENTS WILL HAVE TO BE REDUCED (I.E., SHORTEN MODULE)

Figure 2.2.3-8. Habitat Module Sizing for Lunar Base

OTV-1790

hardware. Projected weight for these modules is between 36,000 and 45,000 lbs. This particular size was chosen because the payload delivery capability of the expendable lunar lander was assumed to be 38,600 lbs. With a 55,000 lb delivery reusable lander it will be possible to use 37 foot 4-segment modules (44,000 to 55,000 lbs) or even the 44 foot 5 segment module (51,000 to 64,000 lbs). The JSC study assumes that the habitat modules are buried in the lunar regolith, which may cause structural and thermal dissipation problems if space station hardware is used. Both problems will tend to drive the module weight higher.

Lunar base logistics missions will provide for crew rotation every 90 days and resupply of expendables. In the early years lunar base activities will be relatively limited in scope so logistics requirements will not be especially high. Delivery of lunar base expandables is not expected to affect OTV flight rates as they can be manifested on propellant delivery flights.

Summary. The lunar mission as described in the JSC LSR study can be accomplished without significant design impacts on the OTV. Performance requirements to get to lunar orbit from low Earth orbit are lower than to get to GEO so manned transfer and most delivery missions could be accomplished with single stages. Delivery of the lunar base habitation modules requires a 2-stage OTV configuration.

Establishing a transportation node in lunar orbit allows more efficient manifesting of propellant and other lunar payloads. This mission approach and an MGSS program are synergistic, with much hardware commonality, and also provide an evolutionary buildup of a manned presence in space.

In the lunar mission timeframe separate manifesting of large system components with on-site integration should be a proven technology, given space station construction and MGSS development. Dependence on the LSS as a transportation node/payload integration center should not cause operational problems.

A lunar lander derived from an OTV design can perform all required lunar missions. This synergism with the OTV program will allow cost-effective development of the lunar lander, increased production runs for major OTV components, and lower operational costs for the OTV program.

Questions that have not been addressed in this study include the servicing-related impacts of the reusable lunar lander and the problems associated with long term storage of cryogenic propellants at an intermittently manned facility. Some servicing or diagnostic equipment could be located at the LSS. If the lander is sufficiently similar to an OTV it could possibly be modified (i.e., attach aerobrake) at the LSS for return to

Earth for overhaul. The possibility of using the lander propulsion system for delivery to the LSS from LEO has also not been analyzed.

2.2.3.3 Trans Lunar Rendezvous Concept

The Trans Lunar Rendezvous (TLR) concept was inspired by a desire to reduce lunar launch requirements by keeping some key assets (i.e., the lunar OTV stage) in permanent orbit in the Earth-Moon system. The original concept proposed by Dr. Buzz Aldrin (TLR-1) was subsequently modified to include a habitat located in cis-lunar space. This second concept (TLR-2) has the following characteristics: (1) space station class habitat and storm shelter during lunar transfer, (2) reduced manned OTV performance requirements, (3) payload integration operations during lunar transfer, and (4) longer lunar transfer times, with subsequently lower OTV delta-V requirements.

The results presented in this study represent a quick analysis of the Trans Lunar Rendezvous concept. The complexity of the TLR orbital mechanics require a more in-depth analysis to fully understand all the TLR mission characteristics. Simulation of TLR orbits using a 3-D, 4-body model would be especially useful. Both TLR concepts are described in the following sections.

As noted earlier, the TLR concepts did not have sufficient benefits relative to the reference lunar program appproach to justify their use.

2.2.3.3.1 Trans Lunar Rendezvous—Type 1

Overview

The Trans Lunar Rendezvous--Type 1 (TLR-1) mission is effectively a two-stage lunar mission where the unfueled second stage called the lunar OTV (LOTV) inert mass is prepositioned in a cis-lunar orbit. The first stage designated as the Earth OTV (EOTV) with lunar payload and a second stage propellant tank module is launched from the LEO Space Station to rendezvous with the inert second stage (LOTV) in low Earth orbit. The payload of the EOTV consists of the lunar payload and propellant for the LOTV. Propellant is then transferred into the empty LOTV tanks and the payload is attached to the LOTV. The first stage (EOTV) then returns to the space station, similar to the reference NASA two-stage lunar mission. The remainder of the mission is similar to the reference mission except during the return leg, where the crew module separates from the LOTV and returns to the Space Station alone (with aeromaneuver), and the LOTV remains in cislunar orbit In the NASA-LSR mission, the crew module remains attached to the OTV at all times.

The key feature of the TLR-1 mission is the LOTV which is permanently based in a cis-lunar orbit. This allows a lower LEO launch mass, which could potentially reduce propellant requirements. However, a quick analysis indicates that there is at least a 6% increase in propellant requirements using the TLR-1 approach relative to the NASA concept. The TLR-1 approach suffers from mismatching of the EOTV and LOTV vehicle sizes and would require two separate OTV development programs. The EOTV requires approximately 115,000 lbm of propellant (LH_2-LO_2) and the LOTV requires approximately 27,000 lbm of propellant, assuming an 80,000 lbm lunar delivery, 15,000 lbm return mission. The EOTV performance requirement is so high that it probably requires a two-stage vehicle, both stages approximately twice as large as the LOTV. On the other hand, a conventional two-stage mission (using identical stages) requires approximately 134,000 lbm of propellant for the same mission. The TLR-1 mission is also subject to a number of factors that were not included in the analysis mentioned above, but which adversely affect its performance. These factors are discussed below:

a. **LEO Rendezvous.** Rendezvous of the EOTV with the LOTV occurs at a relatively low altitude but high energy elliptical orbit. Plane changes must also be made before rendezvous. To minimize the delta-V penalty, the LOTV executes a plane change maneuver (from 18.5° to 28.5° inclination) on its return leg from the Moon. The LOTV perigee is also higher than the Space Station orbit which results in an additional delta-V penalty.

b. **Fast Lunar Transfer.** The TLR-1 orbital periods must coincide with the lunar period (27.3 days), which effectively fixes the available transfer times. The result is a relatively fast lunar transfer (64 hours) with higher energy requirements than would normally be required, especially for unmanned missions. This means that a larger EOTV is required.

c. **Ascending Node Alignment.** The space station orbit will precess at a much higher rate than the LOTV. These precession rates can be synchronized so that both orbit ascending nodes will be aligned once per lunar period by proper selection of orbital parameters. The TLR-1 orbit characteristics are fixed by the Earth-Moon dynamics, so that the Space Station orbit must be changed, either by raising its altitude, or by changing its inclination.

d. **Orbit Perturbations.** The LOTV orbit energy is changed during each lunar pass. The energy must be restored using on-board propulsion systems. Lunar passes occur once per lunar period, independent from the number of lunar missions. The Sun also has a strong perturbing effect.

e. **Delivery.** The LOTV must be delivered to its operational orbit. The cost of this delivery mission must be amortized over the useful life of the LOTV vehicle.

f. **Continuous Operations.** The LOTV is a man-rated vehicle that must operate continuously for many years in the cis-lunar space environment. This will adversely affect debris and radiation shielding requirements as well as overall system reliability. The result is a heavier vehicle that will require a development program separate from EOTV, which is designed for short missions with scheduled maintenance and storage at the space station.

g. **Maintenance.** There are no maintenance facilities available for the LOTV. Maintenance requirements for the LOTV may be more severe than for the EOTV because of its continuous operating mode. Maintenance must either be performed in orbit or from a Lunar Service Station. Both options increase mission logistics requirements, and subsequently reduce useful payload capability.

TLR-1 Mission Profile

The TLR-1 mission uses a payload stack similar to the Apollo lunar mission approach. This approach is also used in the NASA LSR concept and was used in this analysis for comparison purposes. The payload stack contains a command module, a lunar module, a propellant module (for LOTV refueling), and a payload module. It is completely integrated with the EOTV at the space station. During the course of the mission the payload stack is transferred from the Earth-based EOTV to the lunar transfer orbit-based LOTV.

The mission propulsive maneuvers are identified in figure 2.2.3-9. The delta-V budgets for both the TLR-1 and the NASA-LSR concepts are given in table 2.2.3-6. Each major TLR-1 burn is described below:

a. The LOTV orbit is in the Earth-Moon plane, which varies between 18.5° and 28° in 19 year cycles. To avoid large plane change delta-V's at LEO (1000 + fps) a dogleg plane change maneuver is executed on the return leg of the lunar return orbit. The magnitude of this maneuver was not analyzed, but should not exceed a couple hundred fps. This maneuver involves the empty LOTV vehicle only.

b. The perigee of the LOTV orbit (500 nmi) is higher than the space station orbit (270 nmi). A Hohman transfer burn by the EOTV raises its orbit for intersection with the LOTV orbit. The required delta-V is 373 fps. This maneuver involves the EOTV, command module, lunar module, propellant module, and payload module.

c. At LOTV perigee (EOTV apogee) the EOTV burns to accelerate itself and the payload stack to rendezvous velocity with the LOTV. The coplanar delta-V

- Lunar OTV (LOTV) permanently in orbit
- Free return lunar transfer orbit
- Correction burn after each lunar pass
- Change in argument of perigee
- Lunar pass every other LOTV orbit

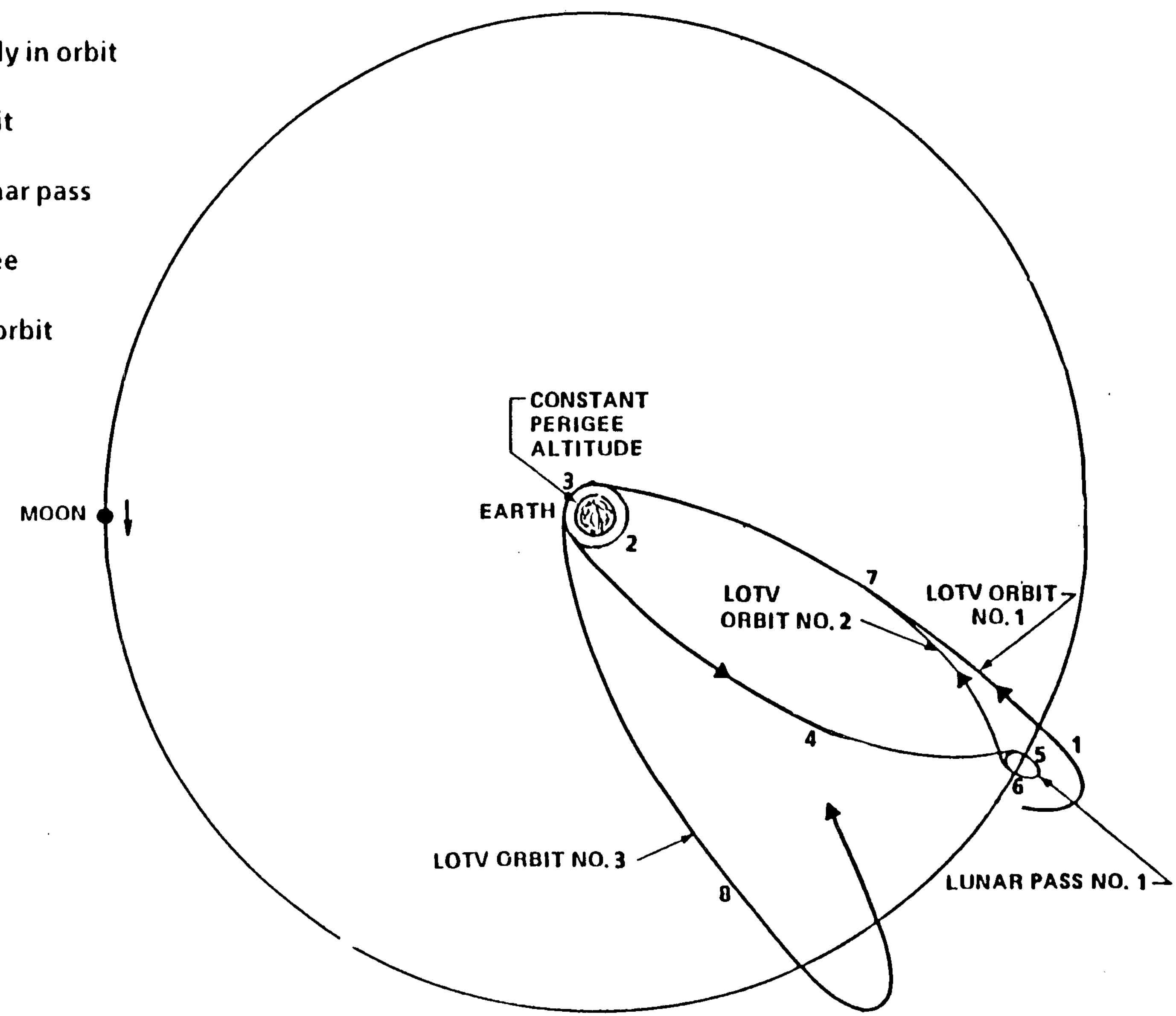


Figure 2.2.3-9 Lunar Transfer Orbit (TLR-1)

OTV-1792

Table 2.2.3-6 Delta-V Budgets

- **80,000 LBS LUNAR DELIVERY**
- **15,000 LBS RETURN**

	TRANS LUNAR RENDEZVOUS	NASA-LUNAR SURFACE RETURN
CIS-LUNAR INJECTION (LEO)	10587 FPS	10109 FPS
MID-COURSE CORRECTION	150	150
LUNAR ORBIT CIRCULARIZATION	3104	2885
LUNAR DE-ORBIT	3104	2885
MID-COURSE CORRECTION	150	150

TLR

EOTV: W_P = 115,000 LBS
LOTV: W_P = 27,000 LBS

LSR

OTV-1: W_P = 67,000 LBS
OTV-2: W_P = 67,000 LBS

OTV-1834

requirement is 10150 fps. The EOTV/payload stack/LOTV are on a 64 hour lunar transfer trajectory. After rendezvous and dock with the LOTV, the payload stack is transferred to the LOTV from the EOTV. The EOTV then separates and lowers its perigee (minimal delta-V) for an aeroassisted return to the space station (with empty propellant module).

d. A midcourse correction of 150 fps is required during cis-lunar coast, including a dog- leg plane change maneuver. The LOTV is refueled with propellant from the payload stack during this period.

e. Upon reaching lunar orbit, the LOTV circularizes itself and the payload stack at 70 nmi. If no plane change is required (e.g. for near-equatorial orbit) then 2575 fps delta-V is required. Polar orbits could require up to 8318 fps. The LOTV is not used for lunar surface operations.

f. After lunar operations are complete, the LOTV payload consists of the command module only. A burn of 2575 fps is required for injection to an Earth return trajectory.

g. A midcourse correction of 150 fps is required during cis-lunar coast, including a dog- leg plane change maneuver. At this time the command module is separated from the LOTV so that it can return to the space station via an aeromaneuver. A small correction burn is required by the LOTV to restore it to a 28.5^{o} inclination, 500 nmi perigee orbit.

h. A dog-leg plane change maneuver is required during the outbound leg of the LOTV orbit to restore the LOTV to its proper orbit in the Earth-Moon plane.

Summary

The potential performance benefits of the TLR-1 approach are counteracted by performance penalties that result from the operational constraints of the LOTV orbit. Payload capability of the TLR-1 mission is less than it is for more conventional mission approaches. The LOTV orbit characteristics cause an operationally complex and inflexible system with few launch opportunities. In addition, the EOTV and LOTV designs are incompatible and would require separate development programs.

2.2.3.3.2 Trans Lunar Rendezvous - Type 2

A variation of the TLR concept was conceived by Boeing personnel and involves a Lunar Transfer Station (LTS) placed permanently in an orbit designed to rendezvous with the Moon once each lunar period. This orbit is essentially a free return orbit similar to those used for Apollo and has a period of approximately one half the lunar period.

Unlike Apollo, the LTS mission requires more than one complete orbit; since a free return orbit does not actually return to Earth with the same orbital parameters as on the outgoing leg, the orbital parameters must be restored so that lunar rendezvous will occur again after two LTS orbits.

The Moon has a strong effect on the LTS orbit. Retrograde orbits lose energy after the lunar pass. Though an orbit can be designed to return to its original perigee, the argument of perigee and the period will change. The change in period must be corrected, but the shift in argument of perigee, as shown in figure 2.2.3-10 reduces the waiting time until the next lunar pass, which is an operational advantage. The timing of the orbit is critical and requires more in-depth analysis to fully understand it.

The transfer orbit as shown in figure 2.2.3-10 is in the plane of the lunar equator. Lunar polar orbits may cause some difficulty but have not been analyzed.

The free return lunar transfer orbit shown in figure 2.2.3-11 is timed so that distortions of the orbit due to the Moon's mass and velocity do not prevent return to Earth. In the case of LTS constant perigee altitude is also maintained. Though some orbital parameters can be specified, period and argument of perigee cannot be maintained without affecting other parameters. The problem is that orbital energy is lost (retrograde) or added (posigrade) with each lunar pass. This energy difference must be counteracted through on-board propulsion on the LTS.

Issues of significance to the TLR-2 concept are described below:

a. The ascending nodes of the space station orbit and the LTS orbit will rarely coincide. The two orbits will precess at different rates and it will be difficult to phase lock the two orbit ascending nodes. The difference in ascending nodes means that there will be a plane change penalty. The space station precession rate can be matched with the LTS only by changing its altitude or its inclination.

b. The inclinations of the space station orbit and the LTS orbit differ and lead to a plane change requirement. The required plane change will vary with calendar date in 19 year cycles. The same plane change is required for all lunar missions; however, rendezvous with the LTS requires that the plane change occur in LEO (where the penalty is high) unlike other mission types where the plane change occurs during cis-lunar transfer (where the penalty is low).

c. The launch window is extremely narrow (approximately one opportunity per month). All missions require launch coordination with both the Moon and the LTS. Other mission types require launch coordination with the Moon only, resulting in a much greater number of launch (and return) windows.

- Lunar Transfer Station (LTS) permanently in orbit
- Free return lunar transfer orbit
- Correction burn after each lunar pass
- Change in argument of perigee
- Lunar pass every other LTS orbit

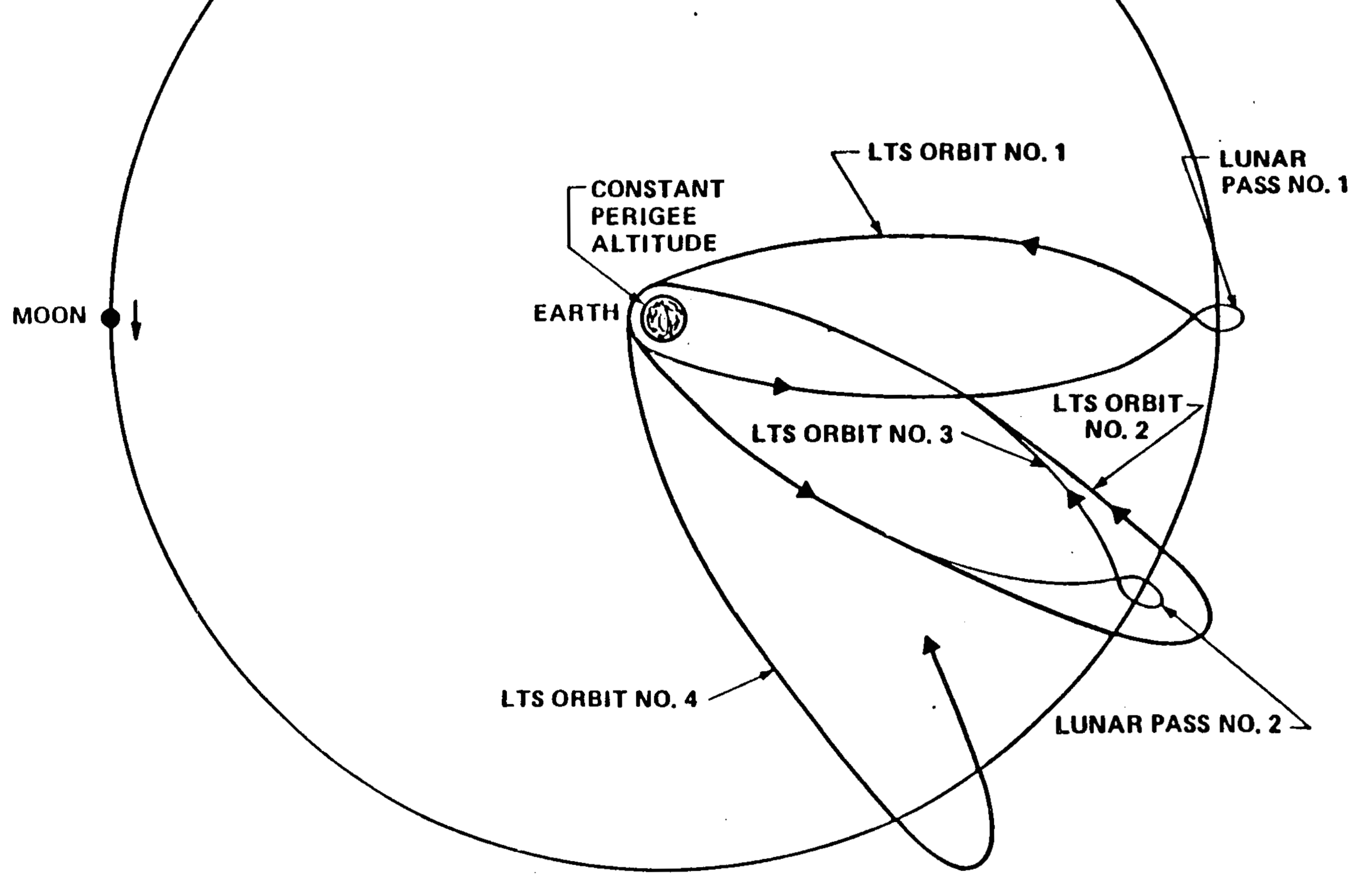


Figure 2.2.3-10 Lunar Transfer Orbit (TLR-2)

- RETROGRADE ORBIT
- SCALE DRAWING
- CONSTANT PERIGEE ALTITUDE
- PERIOD CHANGES AFTER LUNAR PASS
- ARGUMENT OF PERIGEE CHANGES AFTER LUNAR PASS

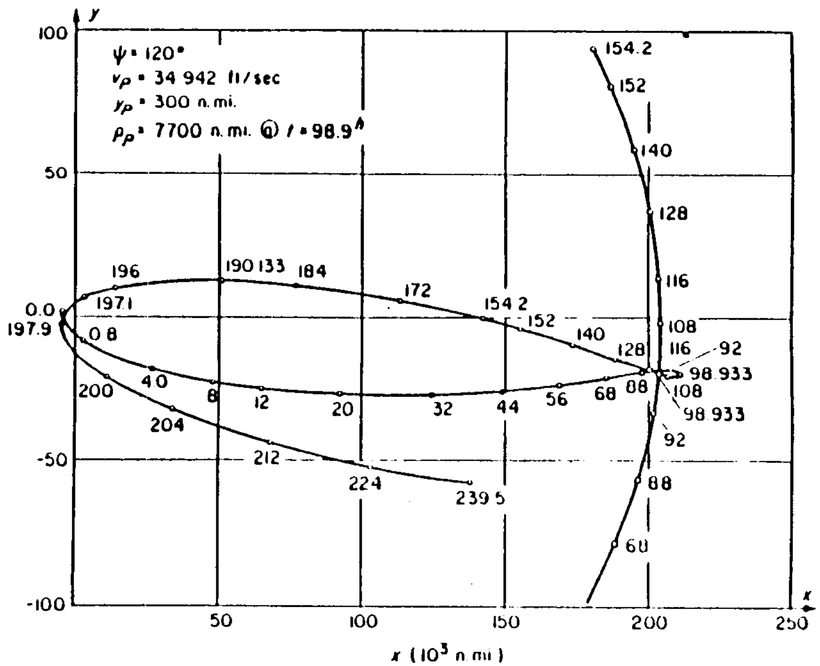


Figure 2.2.3-11 Typical Free Return Lunar Transfer Orbit

OTV-1794

d. Lunar orbit stay-time is limited to the lunar flyby time or multiples of two LTS orbit periods. Other mission types do not have these operational restrictions.
e. The LTS orbit is unstable and requires active correction of orbital parameters after every lunar pass (every other orbit), regardless of whether a mission is being conducted. This places an additional burden on the on-board GNC and RCS systems and on the ground-tracking network.
f. The LTS is subject to repeated passes through the Van Allen belts. The time involved during these passes is relatively short and may not pose a design problem. Radiation exposure affects the LTS power system.

Performance penalties are currently not well understood and require more thorough analysis. Preliminary calculations show a post lunar pass correction of 250 fps (every other LTS orbit) and a lunar transfer injection plane change of more than 1000 fps (required every OTV mission). Analysis of the performance penalties requires a 3-dimensional 3-body (or preferably 4-body) simulation which is currently beyond the scope of the mission analysis task. A variety of issues need to be addressed:

1. Strategies for avoiding LEO plane changes while maintaining the same operational approach (short transfer time in MGSS-type crew module).
2. Strategies for avoiding plane change requirements due to differential nodal regression.
3. Impacts of equatorial and polar lunar trajectories.

The results of these analyses should indicate where, when, and how often propulsive maneuvers should be accomplished, and whether low thrust, high specific impulse systems (e.g., ion thrusters) can be used. This should give a better indication of the actual performance penalties of the TLR-2 approach.

Summary

The TLR-2 approach possesses many potential benefits for the manned lunar mission. The principal one is elimination of the OTV boost of the long duration manned habitat. This can potentially eliminate one single-stage OTV flight for each lunar mission involving delivery of large payloads to the lunar surface. These missions require a multi-stage OTV for payload delivery to lunar orbit, a multi-stage OTV to deliver propellant to land it on the Moon, and a single-stage OTV for the crew. With an LTS, the crew module could be attached to the two-stage OTV.

The LTS operates in a lunar fly-by mode on a predetermined once-monthly schedule. This makes it an attractive option for regularly scheduled missions such as lunar base logistics. On the other hand, the TLR-2 approach does not work very well for unscheduled missions requiring extended lunar orbit operations with duration shorter than one month. Most missions in the pre-2010 time frame fall into this category. This means that if the LTS were to be used, it would become operational in the post-2010 timeframe, which is beyond the scope of the OTV mission model, and would therefore not affect the OTV design.

2.2.4 Planetary

The Boeing OTV Planetary Mission Model (PMM) work was based on the recommendations of the Solar System Exploration Committee of the NASA Advisory Council. This committee proposed that NASA develop a long term program of planetary exploration that would emphasize consistency and low cost. These recommendations are compatible with current government economic policy and are consistent with the capacity of the scientific community to:

1. Design new mission experiments.
2. Monitor missions in process.
3. Effectively and efficiently analyze mission data output.
4. Develop appropriate follow-on mission experiments.

While the political and economic climate for support of planetary missions can be expected to vary over the mission model time period the items listed above are expected to continue to be a significant influence on the scope and frequency of such missions.

The committee's split of funding for planetary exploration beyond 1991 is as follows:

$60M Mission Operations and Data Analysis (MO&DA)

$80M Research and Analysis (R&A)

$160M Specific Program Missions

Planetary Observers ($60M: 37.5%)

Mariner Mark II ($100M: 62.5%)

$300M Total

The proposed Core Program would provide funding for long-term and in-depth analysis of returned data, development of new technology, and a consistent rate of mission activity that would emphasize low cost and efficient use of personnel and technology. Figure 2.2.4-1 shows funding for the Core Program type missions up to 2000.

The committee recommended an annual funding of \$60M (37.5%) for a Planetary Observer Class of missions (inner Planets) and \$100M (62.5%) for Mariner Mark II Class Missions (outer planets). The Core Program is intended to provide:

1. A more even and systematic approach to planetary exploration with a constant annual funding level.
2. Better integration of research, operations, and mission cost requirements in the planning and budget process.
3. Low cost innovative approaches.

The original Boeing OTV PMM developed a range of cost versus time mission schedules that were fitted into a \$160M (FY 1984) annual core program budget for the model time period (1992 to 2010). The NASA Rev. 8 PMM has adopted the same approach with a costs versus time schedule that maintains the cost split between Observer and Mariner Mark II Class missions.

Table 2.2.4-1 shows the cost versus time schedule for the three types of missions used in the PMM. Table 2.2.4-2 shows the Boeing OTV Nominal Observer Class PMM. This model extends the NASA Rev. 7 PMM using data for a Mercury Orbiter in 2009. Table 2.2.4-3 shows the Boeing OTV Nominal Mariner Mark II Class PMM. This model shows projected exploration missions to the outer planets. It extends to 2010 the NASA Rev. 7 Mariner Mark II PMM by adding a Uranus Orbiter in 2008, a Neptune Orbiter in 2005, and a Solar Probe. Figure 2.2.4-2 shows the OTV PMM as a plot of mission cost as a function of time. Launch years for each mission are shown in circled numbers.

Tables 2.2.4-4, 2.2.4-5, 2.2.4-6 and 2.2.4-7 show the <u>OSSA SSE MISSION MODEL</u> described in the NASA Rev. 8 PMM, expanded to the year 2010. These tables were used as the basis for the OTV nominal PMM and give a more complete indication of the full scope of possible planetary missions.

2.2.5 DOD

This section describes the scope of the DOD mission model analysis and the compatibility of the OTV design with DOD operational requirements, specifically basing options.

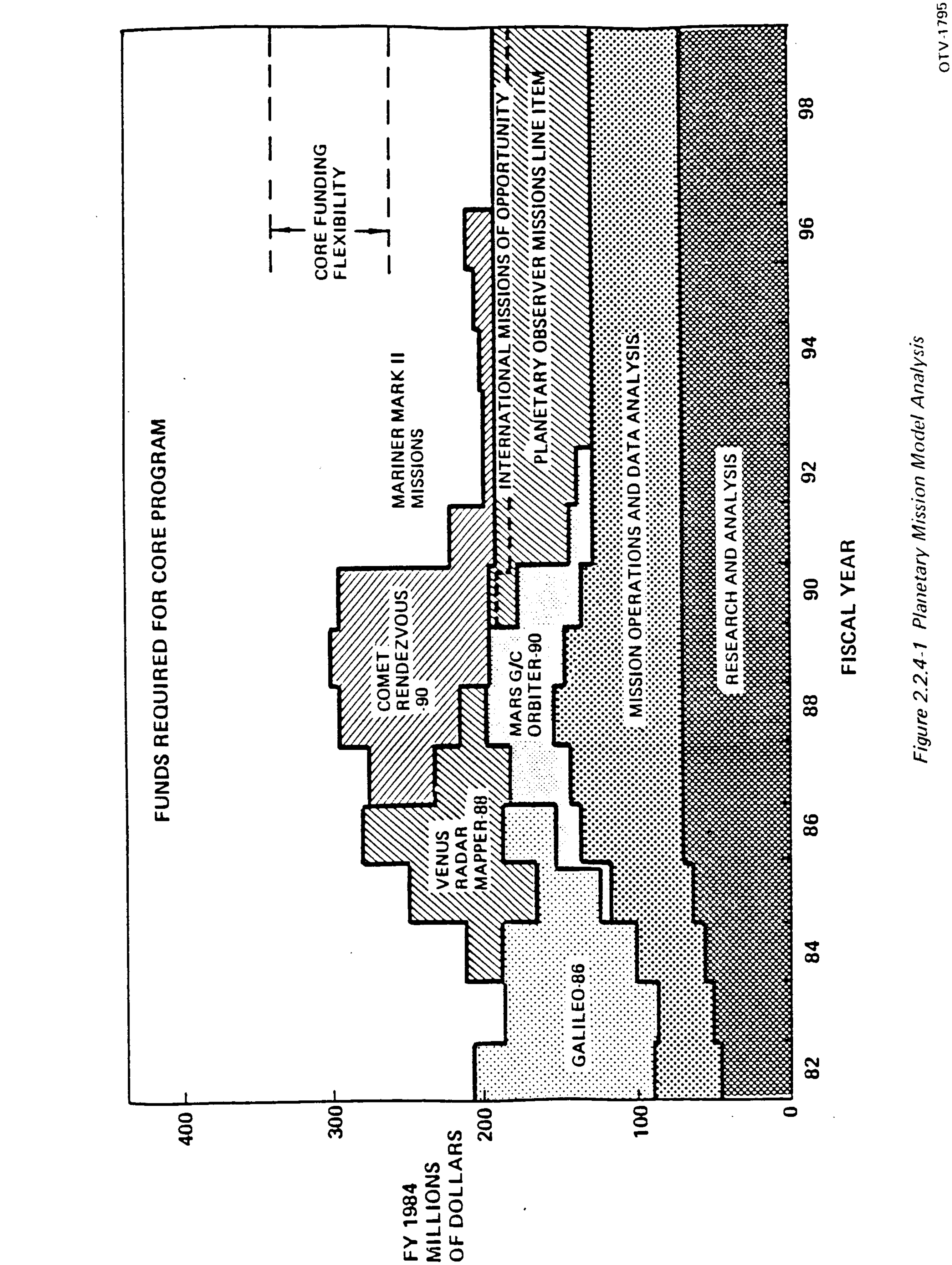


Figure 2.2.4-1 Planetary Mission Model Analysis

Table 2.2.4-1 Solar System Exploration Missions – OSSA Program

OBSERVER CLASS $180M, 5 YRS

YEAR	1	2	3	4	5
COST	20	55	60	35	10

MARINER MARK II $300M, 8 YRS

YEAR	1	2	3	4	5	6	7	8
COST	15	40	60	65	55	40	20	5

AUGMENTATION $700M, 9 YRS (7 YR SPREAD + 10M + 10M)

YEAR	1	2	3	4	5	6	7	8	9
COST	40	115	165	165	120	60	15	10	10

OTV-1796

Table 2.2.4-2 OTV Planetary Mission Model Data Table – Observer Class Missions

OBSERVER CLASS MISSIONS		LENGTH FT.	DIA. FT.	WEIGHT LBS.	C3 KM^2/SEC^2
1. MGCO	MARS GEOSCIENCE CLIMATOLOGY OBSERVER	25	15	3,660	11
2. NEAR	NEAR EARTH ASTEROID RENDEZVOUS	27	13	2,600	22
3. MAO	MARS ACRONOMY OBSERVER	25	15	3,600	11
4. MDN	MARS DUAL NETWORK	25	15	3,600	11
5. VAP	VENUS ATMOSPHERIC PROBE	25	15	3,600	11
6. NEAR	NEAR EARTH ASTEROID RENDEZVOUS	27	13	2,600	22
7. MO	MERCURY ORBITER	25	15	2,200	20

OTV-1797

Table 2.2.4-3 OTV Planetary Mission Model Data Table — Mariner Mark II and Augmented Missions

MARINER MARK II MISSIONS			LENGTH FT.	DIA. FT.	WEIGHT LBS.	C3 KM^2/SEC^2
1.	CR/AF	COMET RENDEZVOUS/ASTEROID FLYBY	26	16	11,000	51
2.	SO/TP	SATURN ORBITER/TITAN PROBE	25	15	2,000	130
3.	MAR	MAINBELT ASTEROID RENDEZVOUS	25	15	7,500	11
4.	SF/P	SATURN FLYBY/PROBE	26	15	2,500	131
5.	NO	NEPTUNE ORBITER /PROBE	25	15	2,500	100
6.	UO	URANUS ORBITER /PROBE	25	16	2,500	90
7.	SP	SOLAR PROBE (HELIOSPHERE MEASUREMENTS TO 0.02 AU)	25	15	2,500	110
AUGMENTED MISSIONS						
11.	MSR	MARS SAMPLE RETURN	35	15	14,333	9
12.	MSR	MARS SAMPLE RETURN	35	16	14,333	9
13.	CNSR	COMET NUCLEUS SAMPLE RETURN	35	16	18,302	73

OTV-1798

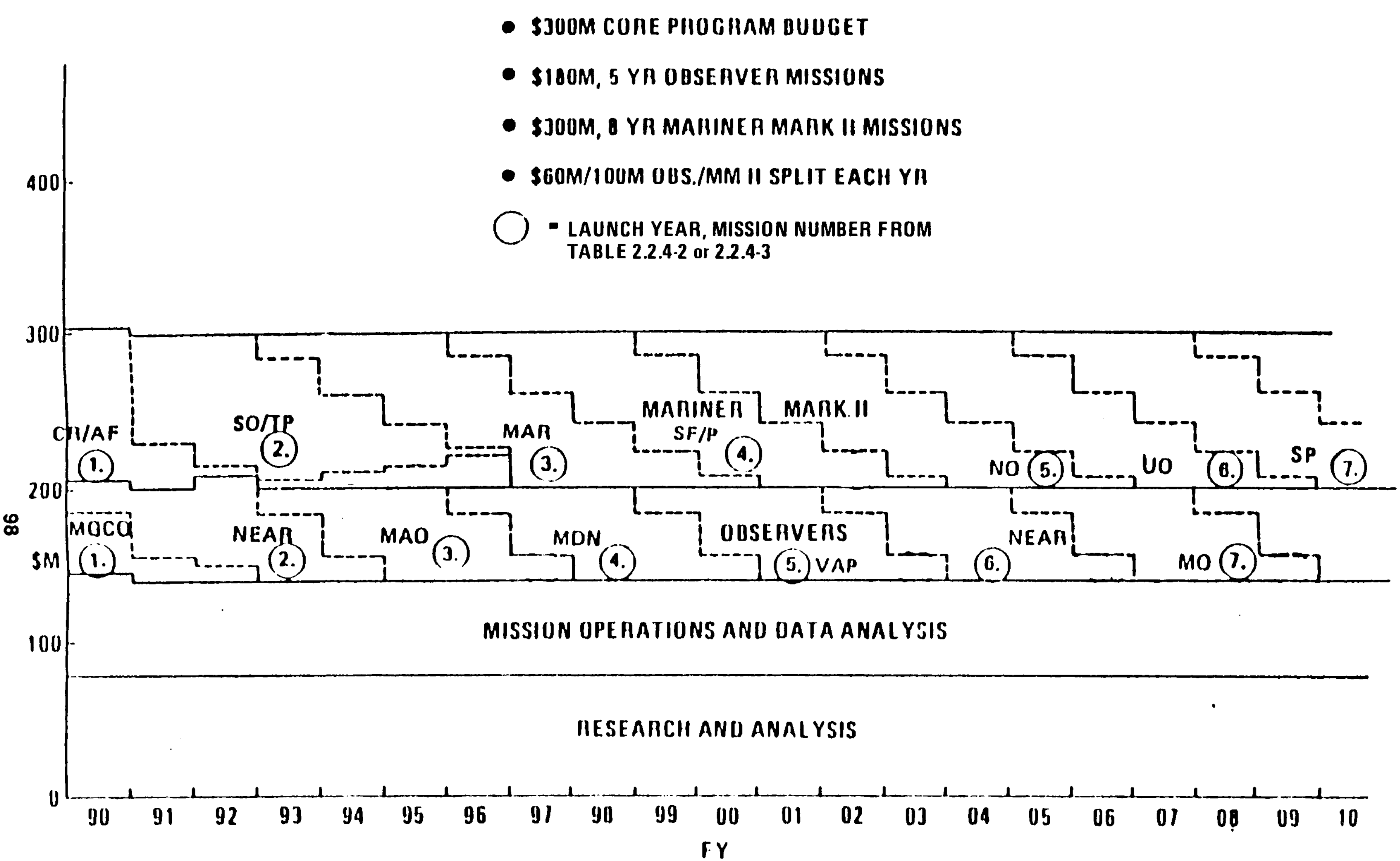


Figure 2.2.4-2 Solar System Exploration Program

OTV-1799

Table 2.2.4-4 Planetary Mission Model Data Table – Observer Class Missions (Modified OSSA SSE)

OBSERVER CLASS MISSIONS		LENGTH FT.	DIA. FT.	WEIGHT LBS.	C3 KM^2/SEC^2
1. MGCO	MARS GEOSCIENCE CLIMATOLOGY OBSERVER	25	15	3,660	11
2. LGO	LUNAR GEOSCIENCE OBSERVER	20	15	6,000	N/A
3. NEAR	NEAR EARTH ASTEROID RENDEZVOUS	27	13	2,600	22
4. MAO	MARS ACRONOMY OBSERVER	25	15	3,600	11
5. MDN	MARS DUAL NETWORK	25	15	3,600	11
6. VAP	VENUS ATMOSPHERIC PROBE	25	15	3,600	11
7. NEAR	NEAR EARTH ASTEROID RENDEZVOUS	27	13	2,600	22
8. MNP	MARS PENETRATOR	25	15	3,600	11
9. VGCO	VENUS GEOSCIENCE CLIMATOLOGY OBSERVER	25	15	3,600	11
10. MO	MERCURY ORBITER	25	15	2,200	28
11. NEAR	NEAR EARTH ASTEROID RENDEZVOUS	27	13	2,600	22

OTV-1800

Table 2.2.4-5 *Planetary Mission Model Data Table – Mariner Mark II and Augmented Missions (Modified OSSA SSE)*

MARINER MARK II MISSIONS			LENGTH FT.	DIA. FT.	WEIGHT LBS.	C3 KM^2/SEC^2
1.	CR/AF	COMET RENDEZVOUS/ASTEROID FLYBY	25	15	11,000	51
2.	SO/TP	SATURN ORBITER/TITAN PROBE	25	15	2,000	130
3.	MAR	MAINBELT ASTEROID RENDEZVOUS	25	15	7,500	11
4.	SF/P	SATURN FLYBY/PROBE	25	15	2,500	131
5.	UF/P	URANUS FLYBY/PROBE	25	15	3,000	143
6.	NF/P	NEPTUNE FLYBY/PROBE	25	15	3,000	TBD
7.	NO	NEPTUNE ORBITER	25	15	2,500	100
8.	MBAO/F	MAINBELT ASTEROID ORBITER/FLYBY	25	15	8,000	11
9.	UO	URANUS ORBITER	25	15		90
10.	SP	SOLAR PROBE (HELIOSPHERE MEASUREMENTS TO 0.02 AU)	25	15	2,500	110
AUGMENTED MISSIONS						
11.	MSR	MARS SAMPLE RETURN	35	15	14,333	9
12.	MSR	MARS SAMPLE RETURN	35	15	14,333	9
13.	CNSR	COMET NUCLEUS SAMPLE RETURN	35	15	18,302	73

OTV-1801

Table 2.2.4-6 Observer Class Mission Model (FY 1984 $)
(Modified OSSA SSE)

MISSION CLASS	NO. NAME	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	PROGRAM COST
OBSERVER	1. MGCO	50	40	15	10																			200*
	2. LGO	60	35	10																				180*
	3. NEAR	20	55	60	35	10																		180
	4. MAO			20	55	60	35	10																180
	5. MDN					20	55	60	35	10														180
	6. VAP							20	55	60	35	10												180
	7. NEAR									20	55	60	35	10										180
	8. MNP											20	55	60	35	10								180
	9. VGCO													20	55	60	35	10						180
	10. MO															20	55	60	35	10				180
	11. NEAR																	20	55	60	35	10		180
ANNUAL COST		130	130	105	100	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	70	70	

*ALL PROGRAM YEARS NOT SHOWN

OTV-1802

Table 2.2.4-7 Mariner Mark II Class and Augmented Mission Models (FY 1984 $) (Modified OSSA SSE)

MISSION CLASS	NO. NAME	FY 89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	PROGRAM COST
MARINER MARK II	1. CR/AF	105	100	30	5	5	10	15	20															415*
	2. SO/TP	40	60	65	55	40	20	5																300*
	3. MAR			15	40	60	65	55	40	20	5													30
	4. SF/P					15	40	60	65	55	40	20	5											300
	5. UF/P							15	40	60	65	55	40	20	5									300
	6. NF/P									15	40	60	65	55	40	20	5							300
	7. NO											15	40	60	65	55	40	20	5					300
	8. MBAO/P													15	40	60	65	55	40	20	5			300
	9. UO															15	40	60	65	55	40	20	5	300
	10. SP																	15	40	60	65	55	40	300*
ANNUAL COST		145	160	110	100	120	135	150	165	150	150	150	150	150	150	150	150	150	150	135	105	65	45	
AUGMENTED MISSIONS	11. MSR-1			40	115	165	165	120	60	15	10	10												700
	12. MSR-2									120	60	15	10	10										215
	13. CNSR						40	115	165	165	120	60	15	10	10									700
ANNUAL COSTS				40	115	165	205	235	225	300	190	85	25	20	10									

*ALL PROGRAM YEARS NOT SHOWN

OTV-1803

Mission Model Assessment

DOD payloads represent the largest single OTV payload category with approximately one third of the OTV launches. Since all DOD payloads are classified it is difficult to present a detailed DOD model assessment in the unclassified arena.

However, the classified DOD model was extrapolated to the year 2010 and payloads were screened on the basis of size and orbital characteristics. This screening process eliminated payloads in low energy orbits and all SDI missions. The SDI payloads were eliminated in large part because their magnitude would justify their own dedicated transportation system and so would not be OTV payload candidates.

An unclassified DOD model was developed with dummy payloads that emulated the payload requirements from the classified model. Though this model could not maintain strict accuracy it was sufficient for the costing analysis.

One significant problem with using the classified model is that it represents official Air Force planning and must therefore be accommodated with existing launch systems (i.e. IUS and Centaur). The impact of the potentially greater payload capacity that would be available with an OTV is therefore not included in the model and no attempt was made to incorporate it.

Basing Options

A list of requirements prepared by the Air Force and given to the study COR was reviewed to assess their impact on the OTV system. These requirements are as follows:

1. Specific DOD missions must be indistinguishable from the ground or the space station.
2. The mating/demating of a DOD payload with/from a space-based OTV will be separate from the Space Station.
3. Survive threat levels up through ASAT encounter (use Sep 84 space TED for threat environment description).
4. 30 to 90 day call-up capability.
5. Responsive launch with 24 hour notice. (Assume the call-up has occurred.)
6. Ground station and communication link availability of 99%.
   a. Interoperability with CSOC.
   b. Secure Communications, Command, and Control
7. Consideration should be given to evolving the space-based OTV from an Unmanned Launch Vehicle/Shuttle Derived Vehicle Upper Stage.

In addition, several important vehicle characteristics were specified: (1) encrypted/anti-jam telemetry, (2) EMP hardening, (3) antonomous operations, (4) low radar cross section, and (5) nuclear (radiation) hardening.

The DOD requirements were not used in the OTV design process. Instead, the OTV design was assessed to determine how effectively it would meet them. An important aspect of this is the preferred basing option for DOD missions. Three different basing options were reviewed, as shown in figure 2.2.5-1. Ground basing the OTV would involve procedures analogous to those used for current launch systems. Two separate space-basing options were analyzed because of the problem of keeping DOD operations separate from civilian operations. When an international space station is the only available space asset, all DOD payload integration must be done at the orbiter, though OTV maintenance and propellant loading could still be done at the station. The alternative is the acquisition of a dedicated DOD platform. The impact of DOD requirements for each of these basing options is shown in table 2.2.5-1.

Of the three available DOD OTV basing options (ground, space station, DOD platform), ground basing is the most attractive with respect to DOD requirements. This is because it minimizes impacts on STS launch scheduling and on-orbit operations, has no performance penalties with respect to unclassified OTV missions, and has the best survivability characteristics against ASAT threats. In addition to this it would also have the most commonality with an SDV upper stage. In all cases the responsive launch requirement implies the need for a dedicated DOD STS and OTV. The OTV is also inherently survivable during all mission segments beyond LEO.

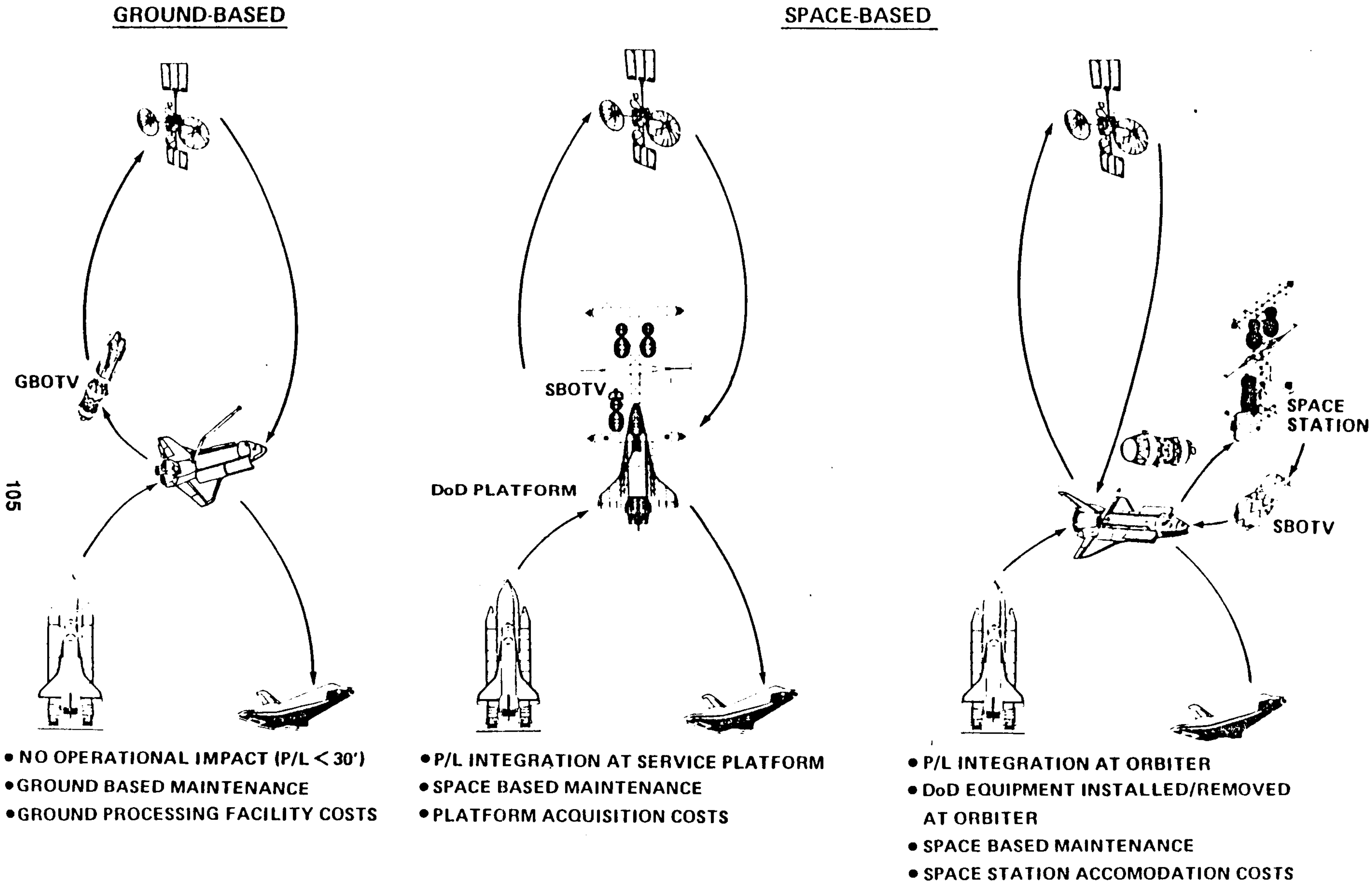


Figure 2.2.5-1 DoD OTV Basing Options

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Table 2.2.5-1 *Impact of DoD Requirements on OTV Systems Options*

DoD REQUIREMENTS	GROUND BASED OPTION	INTERNATIONAL STATION BASING OPTION	DoD PLATFORM BASING OPTION
LAUNCH REQUIREMENTS			
1. INDISTINGUISHABILITY OF SPECIFIC DoD PAYLOADS 2. INTEGRATION SEPARATE FROM SPACE STATION	• ADDITIONAL GROUND PROCESSING REQUIRED • NO SIGNIFICANT PERFORMANCE IMPACT OR TECHNICAL RISK	• ADDITIONAL ASE, EVA & P/L SCARS FOR PAYLOAD INTEGRATION AT ORBITER • 900 FPS ΔV PENALTY ON EACH MISSION FOR OTV ROUND TRIP FROM STATION • PERFORMANCE PENALTY FOR HIGH INCLINATION ORBITS	• ADDITIONAL WEIGHT & DoD CREW TIME REQUIRED TO MAINTAIN PLATFORM AND OTV • PERFORMANCE PENALTY FOR HIGH INCLINATION ORBITS
4. 30–90 DAY CALLUP CAPABILITY 5. 24-HR RESPONSIVE LAUNCH	• PROBABLE STS SCHEDULING IMPACT • POSSIBLE IMPACT ON OTV FLEET SIZING	• PROBABLE IMPACT ON OTV FLEET SIZING AND SPACE STATION ACCOMMODATIONS • MINOR PROPELLANT BOILOFF PENALTY FOR 24-HR HOLD	• DoD OTV AND PLATFORM COST ACCRUED (~$500M) • REDUCTION IN STS MANIFESTING EFFICIENCY PROBABLE
OPERATIONAL REQMTS			
3. SURVIVABILITY 6. COMMUNICATION LINK COMSEC	• VULNERABILITY LIMITED TO STS MISSION SEGMENT • LOW PREEMPTIVE RISK DUE TO GROUND BASING • ADDITIONAL COST AND WEIGHT SCAR ON AVIONICS SUBSYSTEM	• HIGH VULNERABILITY DURING EXTENDED STS MISSION SEGMENT • HIGH PREEMPTIVE RISK (SABOTAGE) • ADDITIONAL COST AND WEIGHT SCAR ON AVIONICS SUBSYSTEM	• HIGH VULNERABILITY DURING EXTENDED STS MISSION SEGMENT • HIGH PREEMPTIVE RISK (ASAT) • ADDITIONAL COST AND WEIGHT SCAR ON AVIONICS SUBSYSTEM
DESIGN REQUIREMENTS			
7. SDV UPPER STAGE COMMONALITY	• DERIVATION FROM SDV UPPER STAGE CAN BE SIMPLE DOWNSIZE (OTHER SUBSYSTEMS PROBABLY APPLICABLE)	• **DERIVATION REQUIRES STRUCTURES REDESIGN (OTHER SUBSYSTEMS MAY BE APPLICABLE)**	• DERIVATION REQUIRES STRUCTURES REDESIGN (OTHER SUBSYSTEMS MAY BE APPLICABLE)

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2.3 DESIGN REFERENCE MISSION MODEL

The mission analysis described in section 2.2 was presented to NASA as an input to the Revision 8 mission model. This model is summarized in table 2.3-1. The key differences with respect to the Boeing model concern the DoD missions and the lunar missions. The DoD missions in the Revision 8 model represent an unclassified average level of activity rather than a reflection of the actual DoD missions. The Revision 8 manned lunar missions retain the JSC-LSR approach (80,000 lb Apollo-type payload stack) but delay initiation of the program until very late in model (2006 nominal model, 2015 low model).

The key missions (all missions are not indicated) from the Revision 8 model that affect the OTV design are shown in figure 2.3-1.

2.4 DESIGN REFERENCE MISSIONS

The objective in this task was to take the key missions from the NASA Revision 8 mission model and provide detailed definition of mission profiles to a level of detail sufficient for derivation of vehicle design requirements.

Payload and mission characteristics data derived from the Revision 8 model was used to abstract mission event sequences and trajectories. The result of this effort was mission sequences giving timelines, delta-V's, and sequenced mass properties for each of the design reference missions (DRM). In all cases, the OTV's are reusable, use a ballute brake for aeroassist, and use LO_2/LH_2 advanced engines.

Design reference missions were assembled by grouping missions sharing common timelines, common event sequences, and common destinations. Within a given mission profile, the actual payloads vary in accordance with the characteristics of the missions incorporated.

The six principal DRM's are: (1) unmanned GEO delivery, (2) molniya delivery, (3) planetary, (4) manned GEO sortie, (5) unmanned lunar delivery, and (6) manned lunar sortie. The DRM descriptions include typical OTV mission profiles and are used as references for the OTV design analysis.

Several simplifying assumptions have been used in deriving the DRM's. These simplifications are necessary because many of the mission characteristics (e.g., number of burns, delta-V's) are significantly affected by the vehicle and payload characteristics. For example, gravity losses depend on thrust to weight ratio, which is determined by the vehicle and payload masses. The severity of the gravity loss affects the optimum number of burns and intermediate apogee/perigee altitudes, which in turn affect the delta-V's. All DRM timelines are based on impulsive burns and two perigee burn

Table 2.3-1 OTV Mission Model Composition Summary

1994 – 2010, REV. 8, 3–31–85

PAYLOAD NO. SERIES	MISSION GROUP	WEIGHT (LB) UP/DOWN	LENGTH (FT)	MISSION MODEL		IOC (LOW/ NOMINAL)
				LOW	NOM	
13000	EXPERIMENTAL GEO PLATFORM	12000/0	30	1	1	2000/1995
13000	OPERATIONAL GEO PLATFORM	20000/0	35	5	6	2004/1998
13000	UNMANNED GEO PLAT. SERVICING	7000/4500	9	1	1	2001/1996
15000	MANNED GEO SORTIE	7500/7500	10	3	17	2008/2002
15000	GEO SERVICE STATION ELEMENTS	13000/0	15 – 20	2	2	2002/1998
15000	GEO SERVICE STA. LOGISTICS	12000/2000	15	5	26	2004/1998
17000	PLANETARY	2000–40000/0	5–35	6	14	1994/1994
17000	UNMANNED LUNAR	5000–20000/0	20	2	2	2007/2001
17000	MANNED LUNAR SORTIE	80,000/15,000	50	0	3	2015/2006
17000	LUNAR BASE ELEMENTS	80,000/0	53	0	3	2020/2008
17000	LUNAR BASE SORTIE/LOGISTICS	80,000/10,000	60	0	6	2021/2009
18000	MULTIPLE GEO PAYLOAD DELIVERY	12000/2000	25	46	79	1994/1994
18000	LARGE GEO SATELLITE DELIVERY	20000/0	20–35	3	7	2001/1997
19000	DOD (GENERIC)	12000–20000 (EQUIV.)		68	85	1994/1994
			SUBTOTALS	142	252	
10100	REFLIGHTS			3	5	1996/1997
			TOTALS	145	257	

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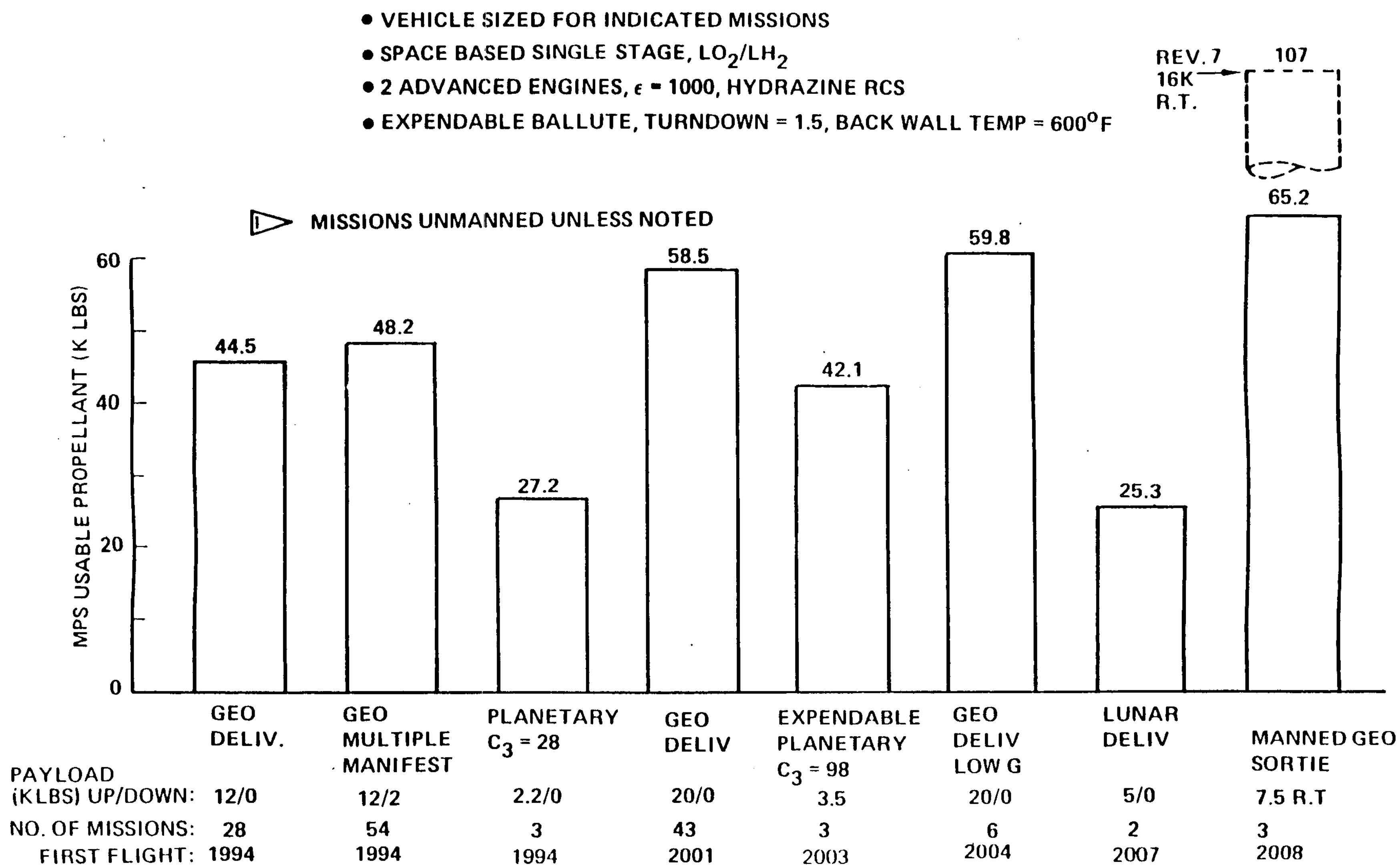

Figure 2.3-1 OTV Sizing for Principal Missions in Rev 8 Low Model 1

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transfers (except multi-stage OTV's). Analysis of several point designs showed two to be close to the optimal number of perigee burns for most missions, so this assumption has been used for all of the DRM's to maintain consistency. In some cases more than two perigee burns will be required (e.g., DRM-5a/DRM-6 multi-stage lunar missions with heavy payloads).

None of the DRM's described in this section use OMV for the final rendezvous and dock at the orbiter or the space station. This is consistent with the final study results, wherein the final rendezvous and dock maneuver is done autonomously with the OTV as indicated in volume 4, section 4.2.2.

2.4.1 DRM-1: Unmanned GEO Delivery

Unmanned GEO delivery is the most common OTV mission. It comprises all communications missions and 60 percent of high energy DoD missions, although for classification concerns all DoD payloads have been expressed in GEO equivalent weights in the Revision 8 model. Of the 142 low model missions (252 nominal), 131 are DRM-1 missions (207 nominal).

The space-based DRM-1 mission profile is shown in figure 2.4.1-1. Key events include LEO deployment (from orbiter or space station), multiple perigee burns (to minimize gravity loss effects), payload delivery and phasing in GEO, GEO deorbit burn, aeromaneuver, back into LEO, and rendezvous and dock (with orbite- or space station). Many of these events are generic to all DRM's and are discussed in more detail in section 3.1.

The DRM-1 sequence of events, timeline, and mass sequencing are given in tables 2.4.1-1 and 2.4.1-2 for the SB OTV and GB OTV respectively. For a given sequence of events, the actual timeline and mass sequence will vary with the OTV configuration. The OTV characteristics (such as which mission sized the propellant capacity and aerobrake) used in generating this data are also given in the tables. In most cases, the mass sequence reflects an off-loaded propellant condition based on one mission (usually MGSS) sizing the propellant capacity.

For analysis purposes the GEO multiple manifest mission was assumed to follow the DRM-1 mission profile, with all payloads delivered simultaneously to one location in GEO.

2.4.2 DRM-2: Molniya Delivery

Approximately 40 percent of high energy DoD missions have Molniya-type orbits (i.e., inclined eccentric orbits). There are 68 DoD missions in the low model and 85 in

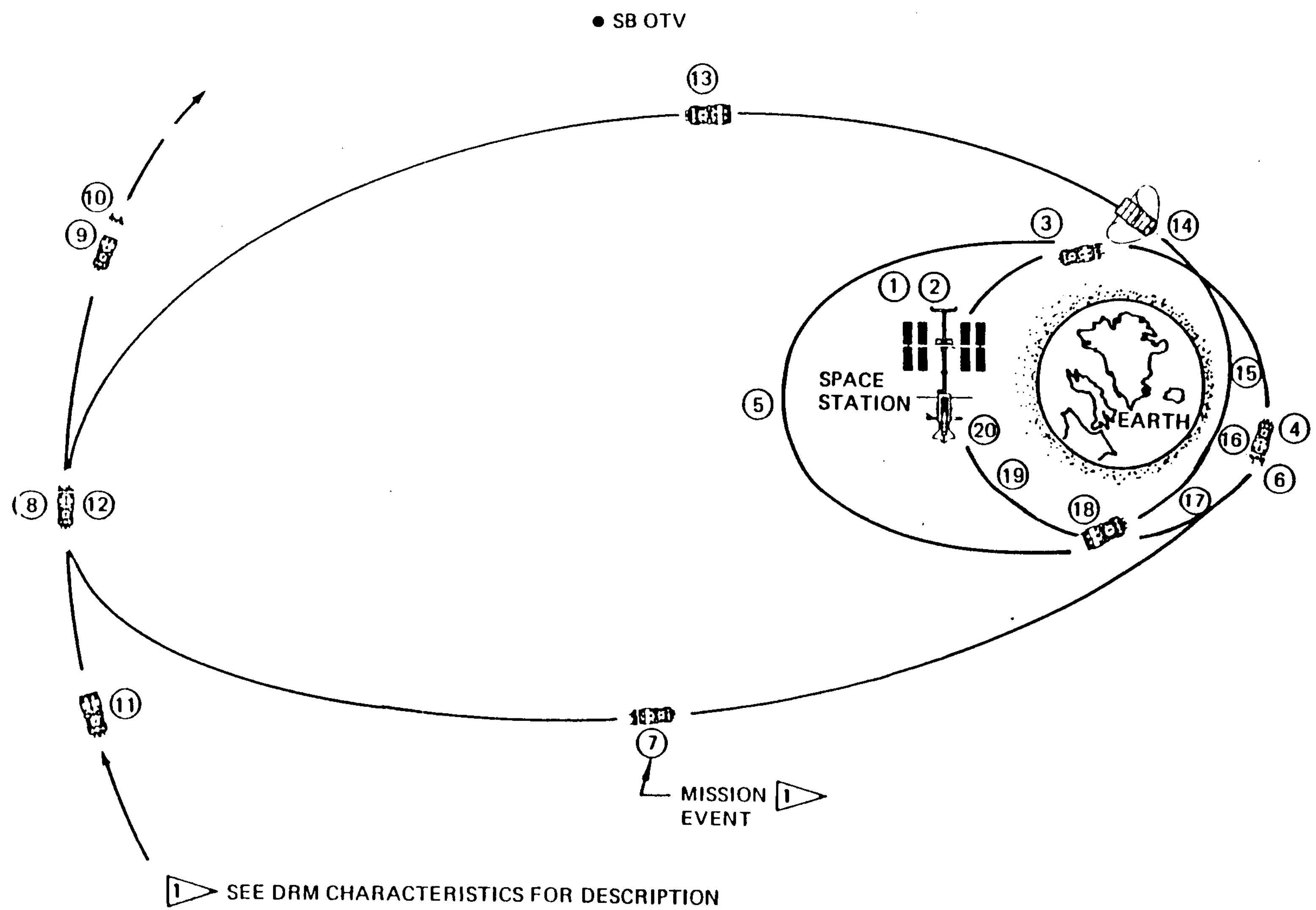

Figure 2.4.1-1 DRM-1: Unmanned GEO Delivery Mission Profile (SB OTV)

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Table 2.4.1-1. DRM-1 Characteristics (SB OTV) GEO Payload Delivery

MISSION/BASING: SPACE BASED GEO UNMANNED (LOW G)
BRAKE: EXPENDABLE BALLUTE (1500 DEG), BALLUTE TURNDOWN RATIO = 1.5
ENGINE: ADVANCED (2), THROTTLED TO G LIMIT = 0.10
PROPULSION: MPS ISP = 481.2, ACS ISP = 220.0
MAIN TANK SIZING: SPACE BASED GEO MANNED MGSS SORTIE
BRAKE SIZING: SPACE BASED GEO UNMANNED (LOW G)
STAGES: 1

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS) MAIN
MAIN STAGE:				
1 DOCKED AT LEO STATION	0.	2.0	-7.	90288.
2 ACS SEPARATION	10.	0.0	-127.	90160.
3 ACS COAST	10.	0.8	-131.	90029.
4 MPS PERIGEE BURN 1 *	3928.	0.2	-20676.	69353.
5 ACS COAST	20.	3.0	-211.	69142.
6 MPS PERIGEE BURN 2 *	3928.	0.2	-15884.	53258.
7 ACS COAST	10.	5.3	-103.	53155.
8 MPS BURN	5798.	0.1	-16621.	36534.
9 ACS PAYLOAD POSITIONING	15.	1.0	-83.	36452.
10 DROP PAYLOAD	0.	0.0	-20000.	16452.
11 ACS COAST	50.	24.0	-240.	16212.
12 MPS DEORBIT BURN	6245.	0.1	-5398.	10814.
13 ACS COAST	10.	6.2	-47.	10767.
14 MPS PRE AERO CORRECT	50.	0.1	-60.	10707.
15 AEROMANEUVER	0.	0.1	-929.	9778.
16 MPS POST AERO CORRECT	251.	0.1	-182.	9596.
17 ACS COAST	10.	0.8	-18.	9578.
18 MPS BURN	420.	0.1	-281.	9298.
19 ACS COAST	10.	0.8	-17.	9280.
20 ACS REND/DOCK	40.	1.0	-57.	9223.

* MAIN STAGE GRAVITY/STEERING LOSS (F/S) = 215.

OTV FLUIDS SUMMARY

MAIN STAGE

MPS USABLE =	60104.	ACS USABLE =	893.	EPS USABLE =	77.
NOMINAL =	58926.	NOMINAL =	812.	NOMINAL =	64.
RESERVES =	1179.	RESERVES =	81.	RESERVES =	13.
BOILOFF =	166.				
START/STOP =	175.				

OTV-1814

Table 2.4.1-2 DRM-1 Timeline (GB OTV)

1:54 PM, 12-JUN-85

START WEIGHT FIXED AT 67889.
STAGE TRENDING: END OF MISSION = 5565. +(0.0647 * MPS USABLE)
BALLUTE TRENDING: JETTISON = 921. +(0.0002 * MPS USABLE)

MISSION/BASING: GROUND BASED GEO UNMANNED
BRAKE: EXPENDABLE BALLUTE (1500 DEG), BALLUTE TURNDOWN RATIO = 1.5
ENGINE: ADVANCED (2), THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0
MAIN TANK SIZING: GROUND BASED GEO UNMANNED
BRAKE SIZING: GROUND BASED GEO UNMANNED
STAGES: 1

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
MAIN STAGE:				MAIN
1 ACS COAST IN 120 NM ORBIT	10.	0.8	-100.	67789.
2 MPS PERIGEE BURN 1 *	3649.	0.2	-14322.	53467.
3 ACS COAST	20.	3.0	-166.	53301.
4 MPS PERIGEE BURN 2 *	4459.	0.2	-13406.	39895.
5 ACS COAST	20.	5.3	-140.	39755.
6 MPS BURN	5865.	0.1	-12510.	27244.
7 ACS PAYLOAD POSITIONING	15.	1.0	-63.	27182.
8 DROP PAYLOAD	0.	0.0	-12065.	15117.
9 ACS COAST	50.	24.0	-230.	14886.
10 MPS DEORBIT BURN	6245.	0.1	-4941.	9945.
11 ACS COAST	10.	6.2	-46.	9899.
12 MPS BURN	50.	0.1	-57.	9842.
13 AEROMANEUVER	0.	0.1	-928.	8914.
14 MPS POST AERO CORRECT	251.	0.1	-167.	8747.
15 ACS COAST	10.	0.8	-17.	8730.
16 MPS BURN	216.	0.1	-145.	8585.
17 ACS COAST	10.	3.0	-28.	8557.

* MAIN STAGE GRAVITY/STEERING LOSS (F/S) = 72.

OTV FLUIDS SUMMARY

MAIN STAGE

MPS USABLE =	46281.	ACS USABLE =	617.	EPS USABLE =	79.
NOMINAL =	45374.	NOMINAL =	561.	NOMINAL =	66.
RESERVES =	907.	RESERVES =	56.	RESERVES =	13.
BOILOFF =	163.				
START/STOP =	175.				

OTV-1815

the nominal model. As explained above, these missions have been expressed as GEO-equivalent payloads in the Revision 8 model. Therefore, DRM-2 has not been used in any of the analysis in this study. It is presented here for completeness because of its importance to the DoD user community.

The space-based DRM-2 mission profile is shown in figure 2.4.2-1. The space-based Molniya mission is particularly difficult for OTV because of a large plane change requirement coupled with misalignment of the ascending nodes of the initial and target orbits. This results in greater propellant requirements for SB OTV payload deliveries than for GB OTV. The space-based DRM-2 mission is characterized by a two segment transfer that includes a very high apogee where the ascending node misalignment is corrected. The DRM-2 sequence of events, timeline, and mass sequencing are given in tables 2.4.2-1 and 2.4.2-2 for the SB OTV and GB OTV, respectively.

2.4.3 DRM-3: Planetary Injection

The DRM-3 mission has the OTV accelerating the payload to the proper C_3, decelerating, and returning to LEO. Planetary missions vary widely in energy (C_3) and payload size. A planetary mission involving 2205 lb, $C_3 = 28$ has been chosen to illustrate the planetary DRM. Planetary missions account for 6 missions in the low model and 14 in the high.

The space-based DRM-3 profile is shown in figure 2.4.3-1. The unique feature of the DRM-3 mission sequence is that it must accelerate to escape velocity before deploying its payload and then decelerate to allow return to Earth. A potential problem associated with this maneuver that has not been addressed in this study is OTV plume impingement on the payload during the deceleration burn. This problem could probably be solved by a cross-track maneuver by the OTV prior to the deceleration burn, but has not been addressed in detail. The DRM-3 sequence of events, timeline, and mass sequencing is given in tables 2.4.3-1 and 2.4.3-2 for the SB OTV and GB OTV respectively.

An alternate approach to planetary missions is to use a kick stage in conjunction with an OTV. The space-based flight profile for this approach (DRM-3a) is shown in figure 2.4.3-2. With DRM-3a, the OTV accelerates to close to escape velocity (e.g., $C_3 = -5$), deploys the payload, and returns to LEO. Then the payload expendable kick stage ignites and accelerates the payload to the proper escape conditions. This DRM was not used for the planetary mission analysis because it is not as cost-effective as DRM-3, due to the cost of throwing away a kick stage on each mission.

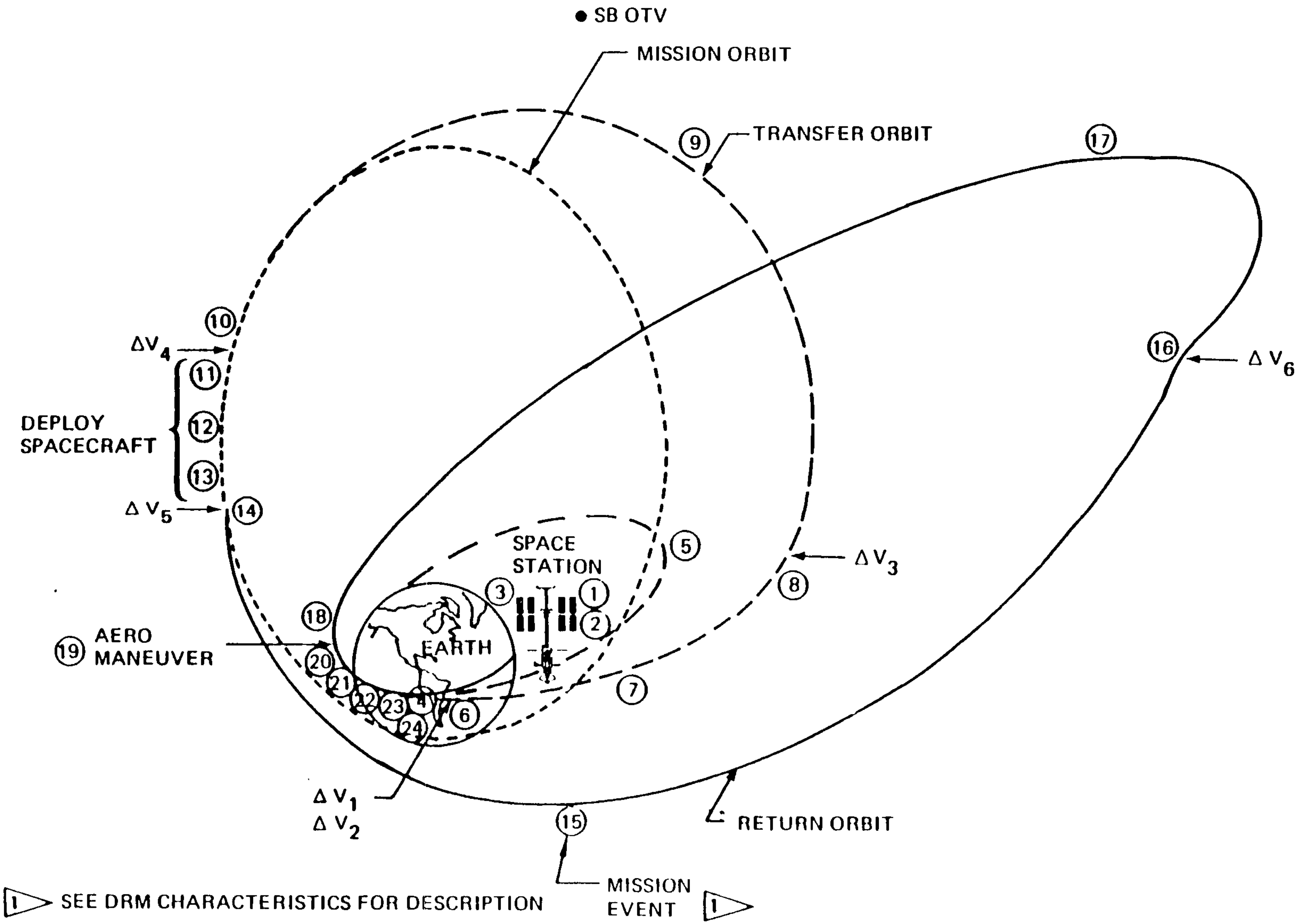


Figure 2.4.2-1 DRM-1: Molniya Delivery Mission Profile (SB OTV)

OTV 1033

Table 2.4.2-1 DRM-2 Timeline (SB OTV)

7:37 PM, 12-JUN-85

MISSION/BASING: SPACE BASED MOLNIYA
BRAKE: EXPENDABLE BALLUTE (15ØØ DEG), BALLUTE TURNDOWN RATIO = 1.5
ENGINE: ADVANCED (2), THRUST = 1ØØØØ.
PROPULSION: MPS ISP = 483.2, ACS ISP = 22Ø.Ø
MAIN TANK SIZING: SPACE BASED GEO UNMANNED MULTIPLE MANIFEST
BRAKE SIZING: SPACE BASED GEO UNMANNED MULTIPLE MANIFEST
STAGES: 1

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
MAIN STAGE:				MAIN
1 DOCKED AT LEO STATION	Ø.	2.Ø	-7.	63039.
2 ACS SEPARATION	1Ø.	Ø.Ø	-89.	62950.
3 ACS COAST	1Ø.	Ø.8	-93.	62857.
4 MPS PERIGEE BURN 1 *	3625.	Ø.2	-13177.	49680.
5 ACS COAST	2Ø.	3.Ø	-156.	49524.
6 MPS PERIGEE BURN 2 *	4256.	Ø.2	-11941.	37583.
7 ACS COAST	1Ø.	2.3	-65.	37518.
8 MPS BURN	4641.	Ø.1	-97Ø1.	27817.
9 ACS COAST	2Ø.	2.3	-9Ø.	27726.
1Ø MPS BURN	2163.	Ø.1	-3623.	24103.
11 ACS COAST	1Ø.	24.6	-162.	23941.
12 ACS PAYLOAD POSITIONING	15.	1.Ø	-56.	23885.
13 DROP PAYLOAD (CAPABILITY)	Ø.	Ø.Ø	-93ØØ.	14585.
14 MPS DEORBIT BURN	3383.	Ø.1	[illegible]	11712.
15 ACS COAST	1Ø.	7.9	-58.	11656.
16 MPS DEORBIT BURN	2575.	Ø.1	-18ØØ.	9855.
17 ACS COAST	1Ø.	24.6	-142.	9714.
18 MPS BURN	5Ø.	Ø.1	-56.	9657.
19 AEROMANEUVER	Ø.	Ø.1	-93Ø.	8727.
2Ø MPS POST AERO CORRECT	251.	Ø.1	-164.	8563.
21 ACS COAST	1Ø.	Ø.8	-16.	8547.
22 MPS BURN	42Ø.	Ø.1	-252.	8295.
23 ACS COAST	1Ø.	Ø.8	-16.	8279.
24 ACS REND/DOCK	4Ø.	1.Ø	-52.	8227.

* MAIN STAGE GRAVITY/STEERING LOSS (F/S) = 57.

OTV FLUIDS SUMMARY

MAIN STAGE

MPS USABLE =	4423Ø.	ACS USABLE =	698.	EPS USABLE =	124.
NOMINAL =	43363.	NOMINAL =	635.	NOMINAL =	104.
RESERVES =	867.	RESERVES =	63.	RESERVES =	21.
BOILOFF =	263.				
START/STOP =	225.				

OTV-1816

Table 2.4.2-2 DRM-2 Timeline (GB OTV)

2:58 AM, 9-JUN-85

START WEIGHT FIXED AT 51609.

MISSION/BASING: GROUND BASED MOLNIYA
BRAKE: EXPENDABLE BALLUTE (1500 DEG), BALLUTE TURNDOWN RATIO = 1.5
ENGINE: ADVANCED (2), THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0
STAGES: 1

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
MAIN STAGE:				MAIN
1 ACS COAST IN 120 NM ORBIT	10.	0.8	-77.	51532.
2 MPS PERIGEE BURN 1 *	3562.	0.2	-10622.	40910.
3 ACS COAST	20.	3.0	-131.	40779.
4 MPS PERIGEE BURN 2 *	4353.	0.2	-10019.	30761.
5 ACS COAST	10.	1.2	-50.	30711.
6 MPS BURN	1627.	0.1	-3074.	27637.
7 ACS COAST	10.	33.9	-215.	27422.
8 ACS PAYLOAD POSITIONING	15.	1.0	-63.	27359.
9 DROP PAYLOAD (CAPABILITY)	0.	0.0	-16130.	11229.
10 MPS BURN	168.	0.1	-145.	11083.
11 ACS COAST	10.	3.2	-32.	11051.
12 MPS BURN	1407.	0.1	-979.	10072.
13 ACS COAST	10.	7.6	-54.	10018.
14 MPS BURN	50.	0.1	-57.	9961.
15 AEROMANEUVER	0.	0.1	-974.	8987.
16 MPS POST AERO CORRECT	251.	0.1	-169.	8819.
17 ACS COAST	10.	0.8	-17.	8802.
18 MPS BURN	216.	0.1	-146.	8656.
19 ACS COAST	10.	3.0	-28.	8628.

* MAIN STAGE GRAVITY/STEERING LOSS (F/S) = 40.

OTV FLUIDS SUMMARY

MAIN STAGE

MPS USABLE =	25511.	ACS USABLE =	421.	EPS USABLE =	98.
NOMINAL =	25011.	NOMINAL =	383.	NOMINAL =	82.
RESERVES =	500.	RESERVES =	38.	RESERVES =	16.
BOILOFF =	202.				
START/STOP =	200.				

OTV-1817

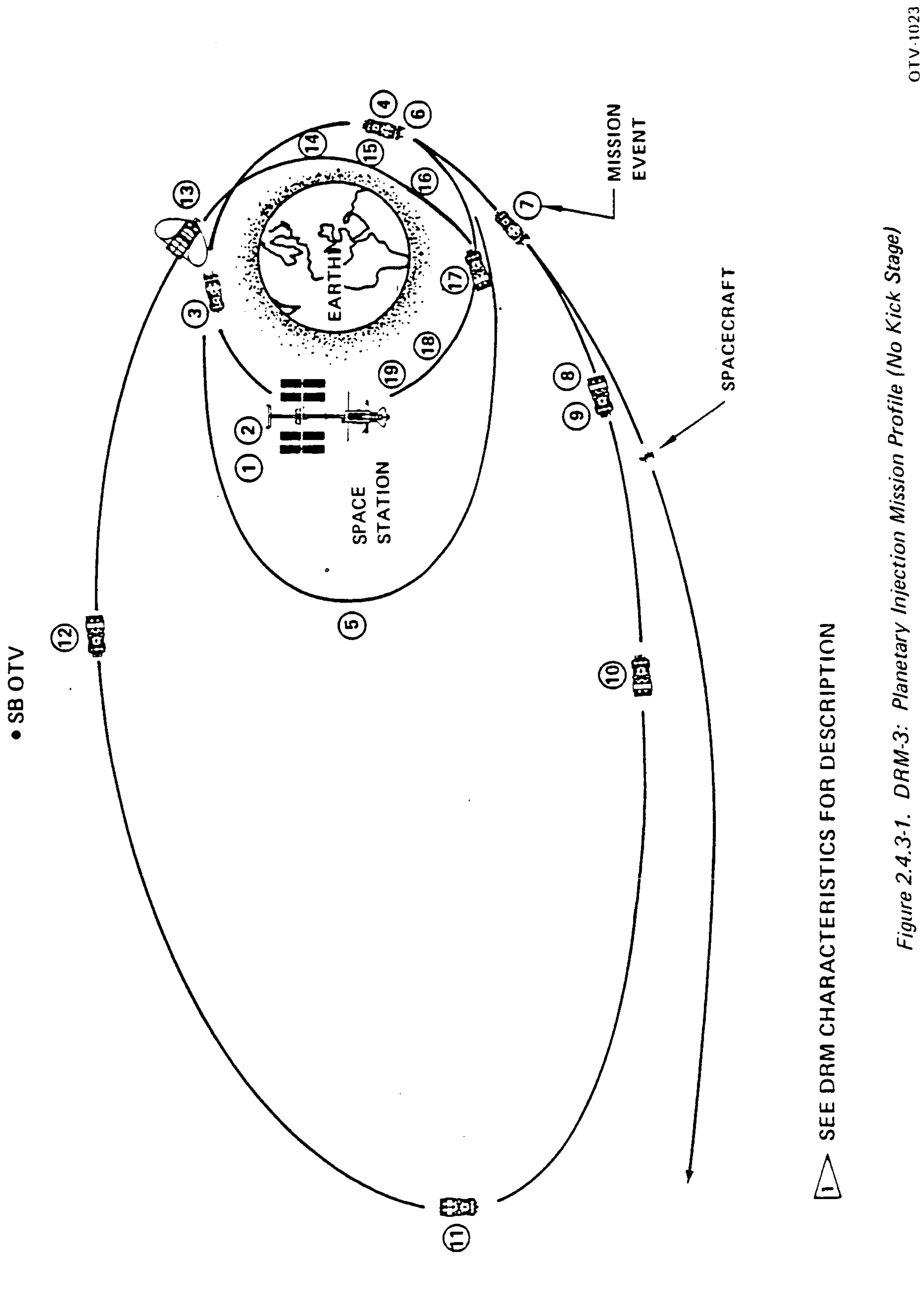


Figure 2.4.3-1. DRM-3: Planetary Injection Mission Profile (No Kick Stage)

Table 2.4.3-1 DRM-3 Timeline (SB OTV)

4:28 PM, MAY 31st, 1985

MISSION/BASING: SPACE BASED PLANETARY, C3 = 28 KM^2/SEC^2
BRAKE: EXPENDABLE BALLUTE (600 DEG), BALLUTE TURNDOWN RATIO = 1.5
ENGINE: ADVANCED (2), THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0
STAGES: 1
VEHICLE SIZING: SPACE BASED GEO UNMANNED (LOW G)
BALLUTE SIZING: SPACE BASED GEO MANNED MGSS SORTIE

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
MAIN STAGE:				MAIN
1 DOCKED AT LEO STATION	0.	2.0	-7.	54108.
2 ACS SEPARATION	10.	0.0	-76.	54031.
3 ACS COAST	10.	0.8	-80.	53951.
4 MPS PERIGEE BURN 1 *	6471.	0.2	-18885.	35065.
5 ACS COAST	20.	6.1	-131.	34935.
6 MPS PERIGEE BURN 2 *	7909.	0.2	-14154.	20781.
7 ACS PAYLOAD POSITIONING	15.	1.0	-49.	20731.
8 DROP PAYLOAD	0.	0.0	-2205.	18526.
9 MPS DEORBIT BURN	4821.	0.1	-4958.	13568.
10 ACS COAST	10.	30.3	-176.	13392.
11 MPS DEORBIT BURN	47.	0.1	-65.	13327.
12 ACS COAST	10.	30.1	-175.	13152.
13 MPS PRE AERO CORRECT	50.	0.1	-67.	13084.
14 AEROMANEUVER	0.	0.1	-3067.	10017.
15 MPS POST AERO CORRECT	251.	0.1	-185.	9832.
16 ACS COAST	10.	0.8	-18.	9814.
17 MPS BURN	420.	0.1	-286.	9528.
18 ACS COAST	10.	0.8	-18.	9511.
19 ACS REND/DOCK	40.	1.0	-59.	9452.

* MAIN STAGE GRAVITY/STEERING LOSS (F/S) = 376.

OTV FLUIDS SUMMARY

MAIN STAGE

MPS USABLE =	39195.	ACS USABLE =	455.	EPS USABLE =	128.
NOMINAL =	38426.	NOMINAL =	414.	NOMINAL =	106.
RESERVES =	769.	RESERVES =	41.	RESERVES =	21.
BOILOFF =	270.				
START/STOP =	175.				

PROPELLANT COEFFICIENTS MPS TOTAL = A +(B * PAYLOAD):
MISSION: PLANETARY, C3 = 28 A = 34868., B = 2.042

OTV-1818

Table 2.4.3-2 DRM-3 Timeline (GB OTV)

10:44 AM, 18-JUN-85

MISSION/BASING: GROUND BASED PLANETARY, C3 = 28 KM^2/SEC^2
BRAKE: EXPENDABLE BALLUTE (1500 DEG), BALLUTE TURNDOWN RATIO = 1.5
ENGINE: ADVANCED (2), THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0
MAIN TANK SIZING: GROUND BASED GEO UNMANNED MULTIPLE MANIFEST
BRAKE SIZING: GROUND BASED GEO UNMANNED MULTIPLE MANIFEST
STAGES: 1

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
MAIN STAGE:				MAIN
1 ACS COAST IN 120 NM ORBIT	10.	0.8	-63.	41774.
2 MPS PERIGEE BURN 1 *	6535.	0.2	-14621.	27153.
3 ACS COAST	20.	6.1	-108.	27045.
4 MPS PERIGEE BURN 2 *	7987.	0.2	-10992.	16053.
5 ACS PAYLOAD POSITIONING	15.	1.0	-39.	16013.
6 DROP PAYLOAD	0.	0.0	-2205.	13808.
7 MPS DEORBIT BURN	4744.	0.1	-3650.	10159.
8 ACS COAST	10.	30.3	-172.	9987.
9 MPS DEORBIT BURN	20.	0.1	-38.	9949.
10 MPS BURN	50.	0.1	-57.	9892.
11 AEROMANEUVER	0.	0.1	-930.	8962.
12 MPS POST AERO CORRECT	251.	0.1	-168.	8794.
13 ACS COAST	10.	0.8	-17.	8778.
14 MPS BURN	216.	0.1	-146.	8632.
15 ACS COAST	10.	3.0	-28.	8604.

* MAIN STAGE GRAVITY/STEERING LOSS (F/S) = 261.

OTV FLUIDS SUMMARY

MAIN STAGE

MPS USABLE =	30087.	ACS USABLE =	229.	EPS USABLE =	76.
NOMINAL =	29497.	NOMINAL =	208.	NOMINAL =	63.
RESERVES =	590.	RESERVES =	21.	RESERVES =	13.
BOILOFF =	155.				
START/STOP =	175.				

PROPELLANT COEFFICIENTS: MPS TOTAL = A + (B * PAYLOAD)
GROUND BASED PLANETARY, C3 = 28 A = 25713., B = 1.991

OTV-1819

• SB OTV

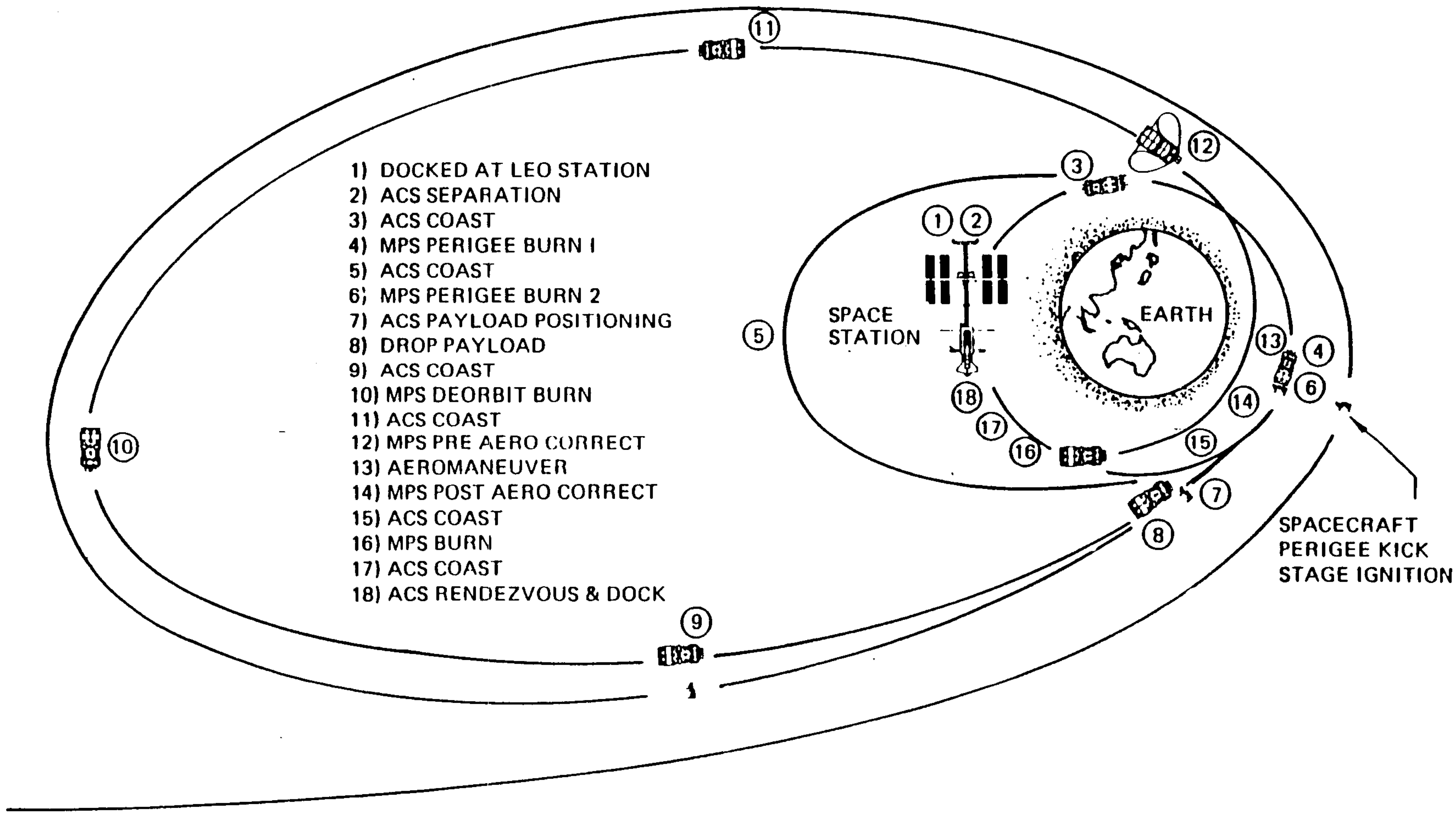


Figure 2.4.3-2. DRM-3a: Planetary Injection Mission Profile (With Kick Stage)

OTV-1032

2.4.4 DRM-4: Manned GEO Sortie

The manned GEO sortie involves manned servicing of 4 satellites with the use of a Mobile GEO Service Station (MGSS). There are 3 manned GEO sorties in the low model and 17 in the nominal. Manned servicing characteristics have been discussed in detail in section 2.2.2.

The space-based DRM-4 profile is shown in figure 2.4.4-1. The key features of the DRM-4 mission include rendezvous and dock with MGSS in GEO, GEO operations performed while docked with MGSS, GEO phasing main propulsive burns performed by OTV (RCS burns by MGSS), long GEO stay time (14 days), and high return payload (crew module). The ground-based manned sortie is also characterized by auxiliary propellant tanks which are needed to meet the performance requirements. The DRM-4 sequence of events, timeline, and mass sequencing is given in tables 2.4.4-1 and 2.4.4-2 for the SB OTV and GB OTV, respectively.

2.4.5 DRM-5: Unmanned Lunar Delivery

The lunar delivery mission is a lower energy mission than GEO delivery. Early missions are single stage (DRM-5), but missions occurring during the Phase II lunar station buildup require multiple stage OTV's (DRM-5a, not shown). There are 2 unmanned lunar deliveries in the low model and 5 in the nominal.

The space-based DRM-5 profile is shown in figure 2.4.5-1. The lunar mission is characterized by a long cis-lunar transfer time during which inertial velocities are low and guidance requirements are high. The trajectory is designed to return to Earth after lunar flyby if lunar rendezvous fails to occur. The lunar transfer trajectory is retrograde with respect to the Moon's orbit and is deflected into a figure-eight shape during the lunar approach. The DRM-5 sequence of events, timeline, and mass sequencing is given in tables 2.4.5-1 and 2.4.5-2 for the SB OTV and GB OTV, respectively.

The SB OTV sequence is reflecting a vehicle sized for the manned sortie mission which is more demanding than the multiple manifest mission for the GB OTV. Accordingly the SB OTV has a heavier dry weight and thus requires more propellant for this lunar mission.

2.4.6 DRM-6: Manned Lunar Sortie

The manned lunar sortie is a lower energy mission than the manned GEO sortie. However, its high payload mass (nominal model 80K lbs out/15K lbs return) requirement

OTV-1024

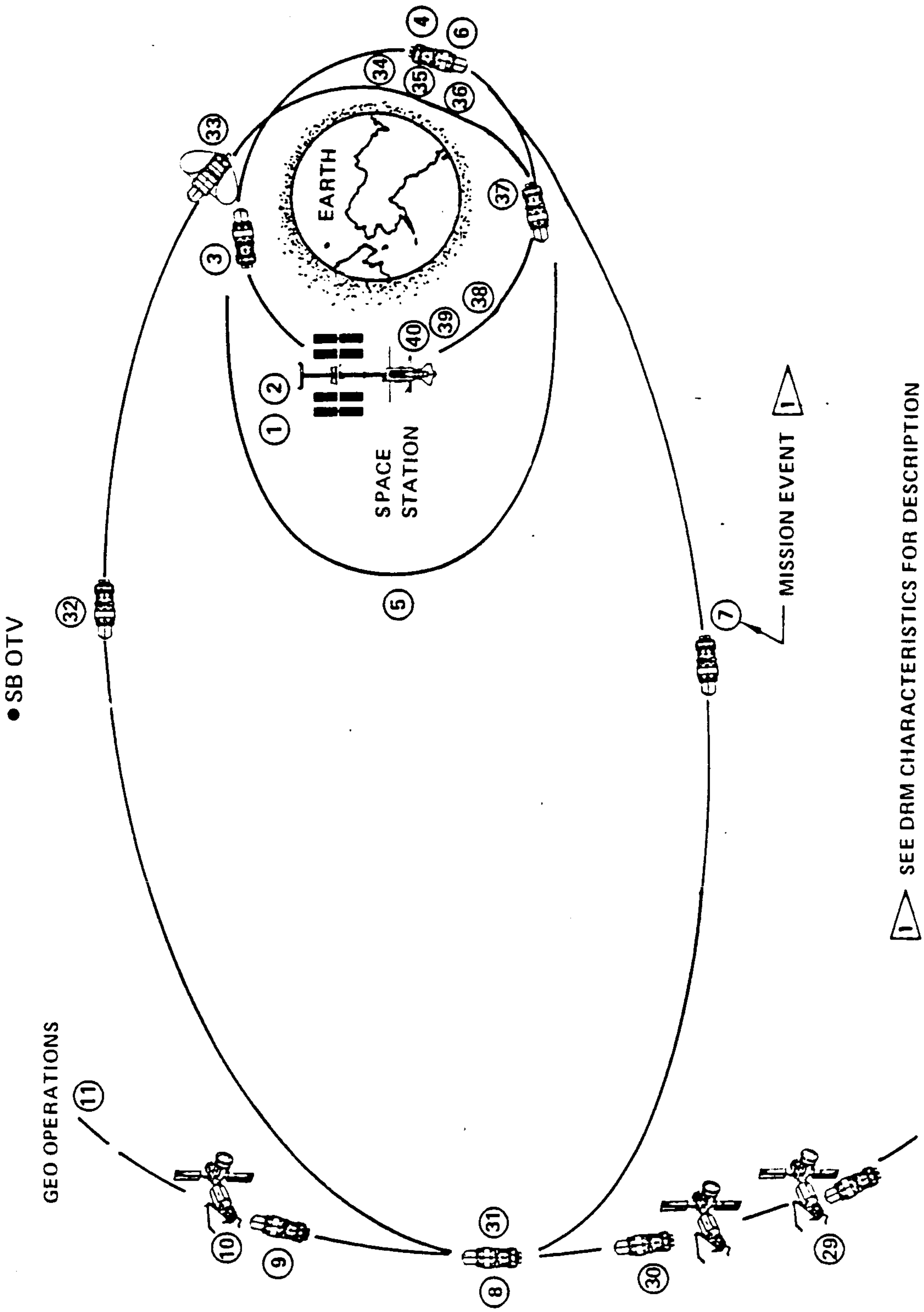


Figure 2.4.4-1. DRM-4: Manned GEO Sortie Mission Profile With MGSS

Table 2.4.4-1 DRM-4 Timeline (SB OTV)

4:28 PM, MAY 31st, 1985

MISSION/BASING: SPACE BASED GEO MANNED MGSS SORTIE
BRAKE: EXPENDABLE BALLUTE (600 DEG), BALLUTE TURNDOWN RATIO = 1.5
ENGINE: ADVANCED (2), THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0, MGSS ISP = 220.0
STAGES: 1
VEHICLE SIZING: SPACE BASED GEO UNMANNED (LOW G)
BALLUTE SIZING: SPACE BASED GEO MANNED MGSS SORTIE

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
MAIN STAGE:				MAIN
1 DOCKED AT LEO STATION	0.	2.0	-7.	86926.
2 ACS SEPARATION	10.	0.0	-123.	86803.
3 ACS COAST	10.	0.8	-127.	86676.
4 MPS PERIGEE BURN 1 *	3600.	0.2	-18153.	68523.
5 ACS COAST	20.	3.0	-209.	68314.
6 MPS PERIGEE BURN 2 *	4256.	0.2	-16541.	51774.
7 ACS COAST	10.	5.3	-101.	51673.
8 MPS BURN	5798.	0.1	-16103.	35570.
9 ACS REND/DOCK	40.	1.0	-206.	35364.
10 ATTACH MGSS	0.	0.0	38234.	73599.
11 MGSS BURN AND OPERATIONS	20.	24.0	-296.	73302.
12 DROP MGSS PAYLOAD	0.	0.0	-426.	72876.
13 MPS BURN	46.	0.1	-240.	72636.
14 MGSS COAST	10.	48.5	-282.	72354.
15 MPS BURN	46.	0.1	-239.	72116.
16 MGSS BURN AND OPERATIONS	60.	24.0	-697.	71419.
17 DROP MGSS PAYLOAD	0.	0.0	-427.	70992.
18 MPS BURN	160.	0.1	-752.	70240.
19 MGSS COAST	10.	126.0	-565.	69676.
20 MPS BURN	160.	0.1	-738.	68937.
21 MGSS BURN AND OPERATIONS	60.	24.0	-670.	68268.
22 DROP MGSS PAYLOAD	0.	0.0	-429.	67839.
23 MPS BURN	46.	0.1	-225.	67613.
24 MGSS COAST	10.	48.5	-275.	67339.
25 MPS BURN	46.	0.1	-224.	67115.
26 MGSS BURN AND OPERATIONS	70.	48.0	-836.	66278.
27 DROP MGSS PAYLOAD	0.	0.0	-427.	65851.
28 MGSS COAST	10.	6.0	-115.	65736.
29 DETACH MGSS	0.	0.0	-34081.	31655.
30 ACS SEPARATION	10.	0.0	-45.	31610.
31 MPS DEORBIT BURN	6245.	0.1	-10474.	21136.
32 ACS COAST	10.	6.2	-62.	21074.
33 MPS PRE AERO CORRECT	50.	0.1	-93.	20982.
34 AEROMANEUVER	0.	0.1	-3067.	17915.
35 MPS POST AERO CORRECT	251.	0.1	-312.	17603.
36 ACS COAST	10.	0.8	-29.	17574.
37 MPS BURN	420.	0.1	-493.	17082.
38 ACS COAST	10.	0.8	-28.	17053.
39 ACS REND/DOCK	40.	1.0	-101.	16952.
40 DROP PAYLOAD	0.	0.0	-7500.	9452.

* MAIN STAGE GRAVITY/STEERING LOSS (F/S) = 97.

OTV FLUIDS SUMMARY

MAIN STAGE

MPS USABLE =	65546.	ACS USABLE =	1025.	EPS USABLE =	34.
NOMINAL =	64260.	NOMINAL =	932.	NOMINAL =	28.
RESERVES =	1285.	RESERVES =	93.	RESERVES =	6.
BOILOFF =	1369.				
START/STOP =	325.				

MGSS ACS NOMINAL = 2444.

PROPELLANT COEFFICIENTS MPS TOTAL = A + (B * PAYLOAD):
MISSION: GEO MANNED MGSS SORTIE A = 44397., B = 3.150

OTV-1820

Table 2.4.4-2 DRM-4 Timeline (GB OTV)

8:46 AM, 15-JUL-85

OTV MPS USABLE PROPELLANT FIXED AT 45376.
BASING/MISSION: GROUND BASED GEO MANNED SORTIE
BRAKE: EXPENDABLE BALLUTE, B/W TEMP = 1500, T/D = 1.5
ENGINE: 2 ADVANCED, THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0, MGS ISP = 220.0
MAIN TANK SIZING: GROUND BASED GEO UNMANNED MULTIPLE MANIFEST
BRAKE SIZING: GROUND BASED GEO MANNED SORTIE
STAGES: 1 WITH REUSABLE AUXILLIARY TANKS

WEIGHTS INPUT

STAGE END = 8863., JETT BALLUTE = 2541., AUX TANK END = 3892.
STAGE TRENDING: END OF MISSION = 5947. + (.0643 * MPS USABLE)
BALLUTE TRENDING: JETTISON = 1975. + (.0180 * AUX TANK USABLE)
AUX TANK TRENDING: END OF MISSION = 1744. + (.0683 * AUX TANK USABLE)

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
1 MPS BURN FROM 120 NM. CIRC	261.	0.1	-1010.	58160.
2 ACS COAST	10.	0.8	-86.	58074.
3 MPS BURN TO 270 NM. CIRC	259.	0.1	-984.	57090.
4 ACS REND/DOCK	40.	1.0	-327.	56763.
5 DOCKED AT LEO STATION	0.	24.0	-89.	56674.
6 ATTACH AUX TANK	0.	0.0	34773.	91448.
7 PICKUP PAYLOAD	0.	0.0	7500.	98948.
8 ACS SEPARATION	10.	0.0	-140.	98808.
9 ACS COAST	10.	0.8	-144.	98664.
10 AUX TANK PERIGEE BURN 1	5623.	0.2	-30881.	67783.
11 ACS COAST	20.	3.0	-207.	67576.
12 MPS PERIGEE BURN 2	2233.	0.2	-9093.	58483.
13 ACS COAST	10.	5.3	-110.	58373.
14 MPS BURN	5798.	0.1	-18189.	40185.
15 ACS REND/DOCK	40.	1.0	-232.	39953.
16 ATTACH MGSS	0.	0.0	38396.	78349.
17 MGSS BURN AND OPERATIONS	20.	24.0	-310.	78039.
18 DROP MGS PAYLOAD	0.	0.0	-426.	77613.
19 MPS BURN	46.	0.1	-254.	77359.
20 MGSS COAST	10.	48.5	-288.	77070.
21 MPS BURN	46.	0.1	-253.	76818.
22 MGSS BURN AND OPERATIONS	60.	24.0	-736.	76081.
23 DROP MGS PAYLOAD	0.	0.0	-427.	75654.
24 MPS BURN	160.	0.1	-799.	74855.
25 MGSS COAST	10.	126.0	-571.	74284.
26 MPS BURN	160.	0.1	-785.	73498.
27 MGSS BURN AND OPERATIONS	60.	24.0	-708.	72790.
28 DROP MGS PAYLOAD	0.	0.0	-429.	72361.
29 MPS BURN	46.	0.1	-239.	72122.
30 MGSS COAST	10.	48.5	-281.	71841.
31 MPS BURN	46.	0.1	-237.	71604.
32 MGSS BURN AND OPERATIONS	70.	48.0	-880.	70724.
33 DROP MGS PAYLOAD	0.	0.0	-427.	70297.
34 MGSS COAST	10.	6.0	-121.	70175.
35 DETACH MGSS	0.	0.0	-34081.	36094.
36 ACS SEPARATION	10.	0.0	-51.	36043.
37 MPS DEORBIT BURN	6245.	0.1	-11940.	24103.
38 ACS COAST	10.	6.2	-66.	24037.
39 MPS BURN	50.	0.1	-102.	23934.
40 AEROMANEUVER	0.	0.1	-2541.	21393.
41 MPS POST AERO CORRECT	251.	0.1	-367.	21025.
42 ACS COAST	10.	0.3	-34.	20992.
43 MPS BURN	420.	0.1	-584.	20408.
44 ACS COAST	10.	0.3	-33.	20375.
45 ACS REND/DOCK	40.	1.0	-120.	20255.
46 DROP PAYLOAD	0.	0.0	-7500.	12755.
47 DETACH AUX TANK	0.	0.0	-3892.	8863.

GRAVITY/STEERING LOSS (F/S) = 217.

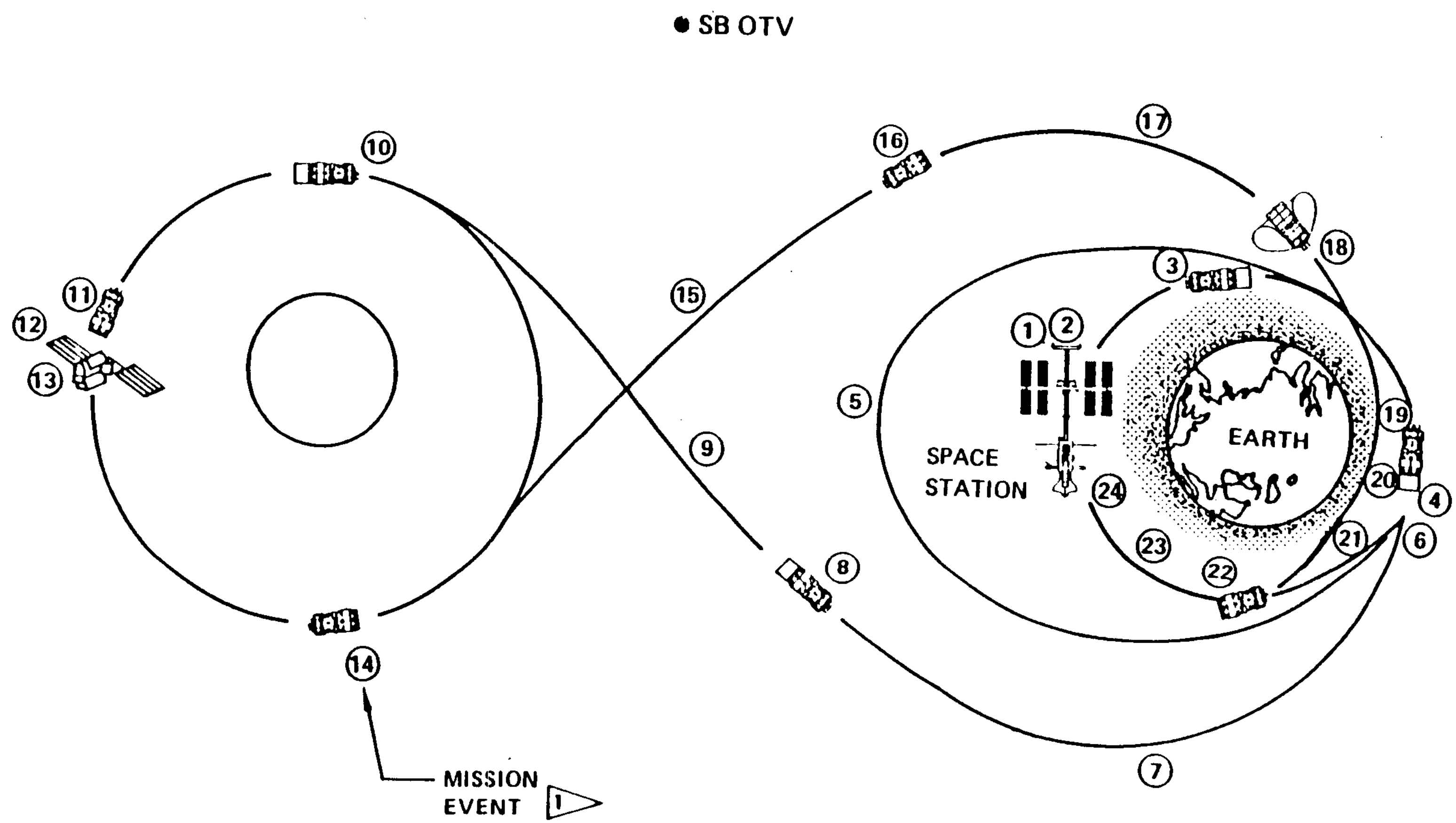
PROPELLANT SUMMARY

MPS TOTAL PROPELLANT = 79425.

MPS USABLE	= 45376.	ACS USABLE	= 1585.	EPS USABLE	= 37.
NOMINAL	= 44486.	NOMINAL	= 1441.	NOMINAL	= 31.
RESERVES	= 890.	RESERVES	= 144.	RESERVES	= 6.
BOILOFF	= 1457.				
START/STOP	= 375.				

AUXILLIARY TANKS
USABLE = 31473.
NOMINAL = 30856.
RESERVES = 617.

MGS NOMINAL = 2606.



1 SEE DRM CHARACTERISTICS FOR DESCRIPTION

Figure 2.4.5-1 DRM-5: Unmanned Lunar Delivery (SB OTV)

OTV 1030

Table 2.4.5-1 DRM-5 Timeline (SB OTV)

10:09 AM, 9-JUL-85

BASING/MISSION: SPACE BASED LUNAR UNMANNED
BRAKE: EXPENDABLE BALLUTE, D/W TEMP = 1500, T/D = 1.5
ENGINE: 2 ADVANCED, THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0
STAGES: 1

WEIGHTS INPUT

STAGE END = 9229., JETT BALLUTE = 932.

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
1 DOCKED AT LEO STATION	0.	2.0	-7.	46610.
2 ACS SEPARATION	10.	0.0	-66.	46544.
3 ACS COAST	10.	0.8	-70.	46474.
4 MPS PERIGEE BURN 1 *	4559.	0.2	-11911.	34563.
5 ACS COAST	20.	3.0	-113.	34450.
6 MPS PERIGEE BURN 2 *	5571.	0.2	-10445.	24004.
7 ACS COAST	10.	60.0	-345.	23659.
8 MPS MIDCOURSE CORRECTION	160.	0.1	-267.	23392.
9 ACS COAST	10.	60.0	-345.	23047.
10 MPS BURN	2536.	0.1	-3490.	19557.
11 ACS PAYLOAD POSITIONING	15.	1.0	-47.	19511.
12 DROP PAYLOAD	0.	0.0	-5000.	14511.
13 ACS LUNAR OPERATIONS	10.	168.0	-893.	13618.
14 MPS BURN	2536.	0.1	-2071.	11547.
15 ACS COAST	10.	60.0	-328.	11219.
16 MPS MIDCOURSE CORRECTION	160.	0.1	-140.	11079.
17 ACS COAST	10.	60.0	-327.	10752.
18 MPS BURN	50.	0.1	-59.	10693.
19 AEROMANEUVER	0.	0.1	-932.	9761.
20 MPS POST AERO CORRECT	216.	0.1	-159.	9601.
21 ACS COAST	10.	0.8	-18.	9584.
22 MPS BURN	420.	0.1	-280.	9304.
23 ACS COAST	10.	0.8	-17.	9287.
24 ACS REND/DOCK	40.	1.0	-58.	9229.

GRAVITY/STEERING LOSS (FPS) = 70.

PROPELLANT SUMMARY

MPS TOTAL PROPELLANT = 31277.

MPS USABLE =	29170.	ACS USABLE =	512.	EPS USABLE =	748.
NOMINAL =	28598.	NOMINAL =	466.	NOMINAL =	623.
RESERVES =	572.	RESERVES =	47.	RESERVES =	125.
BOILOFF =	1544.				
START/STOP =	225.				

OTV-1804

Table 2.4.5-2 DRM-5 Timeline (GB OTV)

10:11 AM, 9-JUL-85

BASING/MISSION: GROUND BASED LUNAR UNMANNED
BRAKE: EXPENDABLE BALLUTE, B/W TEMP = 1500, T/D = 1.5
ENGINE: 2 ADVANCED, THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0
STAGES: 1

WEIGHTS INPUT

STAGE END = 8604., JETT BALLUTE = 930.

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)
1 ACS COAST IN 120 NM ORBIT	10.	0.8	-68.	45287.
2 MPS PERIGEE BURN 1 *	4658.	0.2	-11822.	33465.
3 ACS COAST	20.	3.0	-110.	33355.
4 MPS PERIGEE BURN 2 *	5692.	0.2	-10294.	23061.
5 ACS COAST	10.	60.0	-344.	22717.
6 MPS MIDCOURSE CORRECTION	160.	0.1	-257.	22460.
7 ACS COAST	10.	60.0	-343.	22116.
8 MPS BURN	2536.	0.1	-3350.	18766.
9 ACS PAYLOAD POSITIONING	15.	1.0	-45.	18721.
10 DROP PAYLOAD	0.	0.0	-5000.	13721.
11 ACS LUNAR OPERATIONS	10.	168.0	-892.	12830.
12 MPS BURN	2536.	0.1	-1952.	10877.
13 ACS COAST	10.	60.0	-327.	10550.
14 MPS MIDCOURSE CORRECTION	160.	0.1	-133.	10418.
15 ACS COAST	10.	60.0	-326.	10091.
16 MPS BURN	50.	0.1	-57.	10034.
17 AEROMANEUVER	0.	0.1	-930.	9104.
18 MPS POST AERO CORRECT	216.	0.1	-150.	8954.
19 ACS COAST	10.	0.8	-17.	8937.
20 MPS BURN	420.	0.1	-263.	8674.
21 ACS COAST	10.	0.8	-16.	8658.
22 ACS REND/DOCK	40.	1.0	-54.	8604.

GRAVITY/STEERING LOSS (FPS) = 70.

PROPELLANT SUMMARY

MPS TOTAL PROPELLANT = 30709.

MPS USABLE	= 28614.	ACS USABLE	= 421.	EPS USABLE	= 748.
NOMINAL	= 28053.	NOMINAL	= 382.	NOMINAL	= 623.
RESERVES	= 561.	RESERVES	= 38.	RESERVES	= 125.
BOILOFF	= 1537.				
START/STOP	= 225.				

OTV-1805

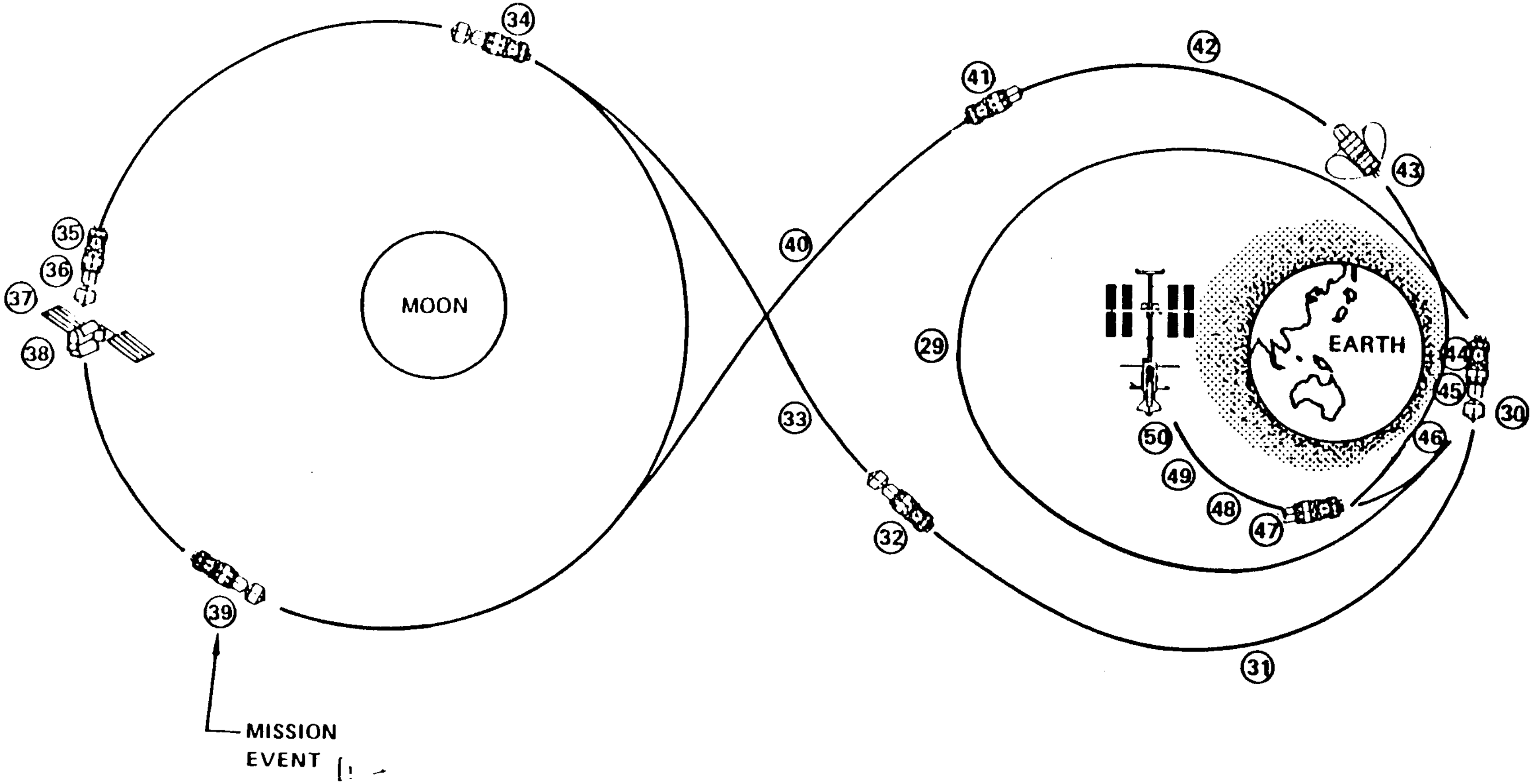
drives the OTV to a multiple stage configuration (3 stages for SB OTV and 4 stages for GB OTV). There are no manned lunar sorties in the low model and 9 in the nominal.

The space-based DRM-6 profile is shown for the third stage only in figure 2.4.6-1. The function of the first two stages is limited to raising the perigee velocity as shown in figure 2.4.6-2. The manned lunar mission is characterized by a long cis-lunar transfer time (as described in 2.4.5), multiple staging, and a crew module return to Earth. Most of the energy advantage the manned lunar mission has over the manned GEO mission is due to the high DRM-6 atmospheric reentry velocities that are dissipated by the aeromaneuver. The DRM-6 sequence of events (for all stages), timeline, and mass sequencing is given in tables 2.4.6-1 and 2.4.6-2 for the SB OTV and GB OTV, respectively. It should be noted that the SB OTV uses 3 stages and the GB OTV uses 4 stages.

2.5 MISSION ANALYSIS SUMMARY

The mission analysis task examined the NASA Rev. 7 mission model and identified a number of areas that could be improved. This review was followed by in-depth analyses of the communications, GEO servicing, lunar, planetary, and DOD mission categories. The GEO servicing analysis, in particular, developed a new approach to both manned and unmanned servicing that allowed substantial reductions in OTV performance requirements and servicing costs. The GEO servicing model and the planetary model were subsequently incorporated into the NASA Rev. 8 model, as well as some elements of the communications model. The analysis resulted in a credible mission model that provides a firm basis for the OTV design and cost analysis.

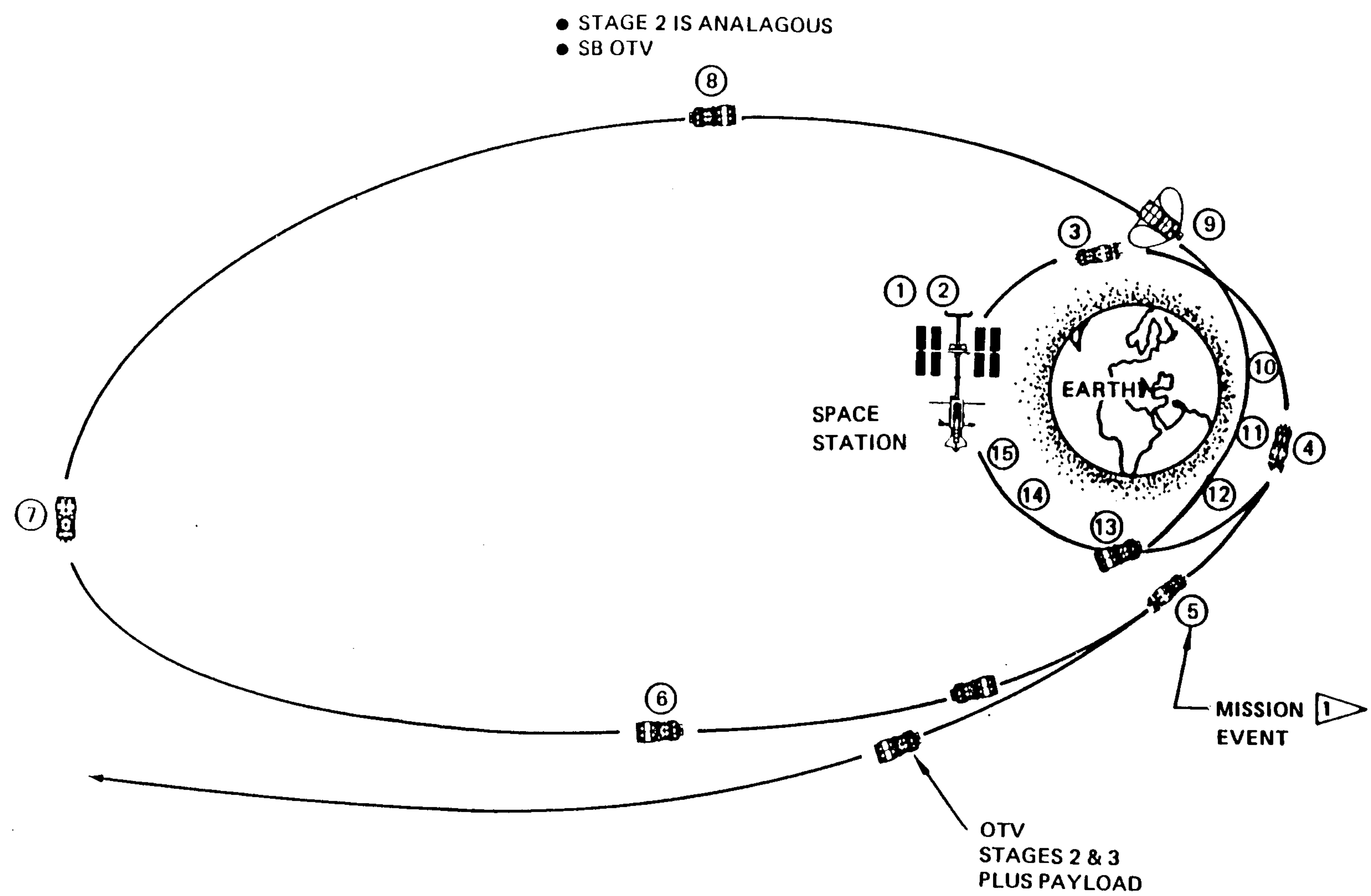
● SB OTV



SEE DRM CHARACTERISTICS FOR DESCRIPTION

Figure 2.4.6-1 DRM-6: Manned Lunar Sortie (Stage 3)

OTV-1025



1 SEE DRM CHARACTERISTICS FOR DESCRIPTION

Figure 2.4.6-2 DRM-6: Manned Lunar Sortie (Stage I)

OTV-1021

Table 2.4.6-1 DRM-6 Timeline (SB OTV)

7:21 AM, 1-JUL-85

BASING/MISSION: SPACE BASED LUNAR MANNED
BRAKE: EXPENDABLE BALLUTE, B/W TEMP = 1500, T/D = 1.5
ENGINE: 2 ADVANCED, THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0
MAIN TANK SIZING: SPACE BASED GEO MANNED SORTIE
BRAKE SIZING: SPACE BASED LUNAR MANNED
STAGES: 3

WEIGHTS INPUT

STAGE 1
STAGE END = 10128., JETT BALLUTE = 932.

STAGE 2
STAGE END = 10128., JETT BALLUTE = 932.

STAGE 3
STAGE END = 9494., JETT BALLUTE = 2156.

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)	
STAGE 1					
1 123 DOCKED AT LEO STATION	0.	2.0	-28.	287165.	
2 123 ACS SEPARATION	10.	0.0	-405.	286760.	
3 123 ACS COAST	10.	0.8	-417.	286342.	
4 123 MPS PERIGEE BURN 1 •	3376.	0.2	-64167.	222176.	← DROP PAYLOAD
5 1 ACS STAGING BURN	10.	0.0	-17.	12036.	
6 1 ACS COAST	10.	1.3	-24.	12013.	
7 1 MPS DEORBIT BURN	315.	0.0	-265.	11747.	
8 1 ACS COAST	10.	1.3	-23.	11724.	
9 1 MPS BURN	50.	0.1	-63.	11661.	
10 1 AEROMANEUVER	0.	0.1	-932.	10729.	
11 1 MPS POST AERO CORRECT	251.	0.1	-196.	10533.	
12 1 ACS COAST	10.	0.8	-19.	10514.	
13 1 MPS BURN	420.	0.1	-305.	10209.	
14 1 ACS COAST	10.	0.5	-19.	10191.	
15 1 ACS REND/DOCK	40.	1.0	-63.	10128.	
STAGE 2					
16 23 ACS COAST	20.	2.6	-620.	209503.	
17 23 MPS PERIGEE BURN 2 •	3376.	0.2	-44281.	165222.	← DROP PAYLOAD
18 2 ACS STAGING BURN	10.	0.0	-17.	11961.	
19 2 ACS COAST	10.	3.3	-34.	11927.	
20 2 MPS BURN	198.	0.0	-170.	11757.	
21 2 ACS COAST	10.	3.3	-34.	11724.	
22 2 MPS BURN	50.	0.1	-63.	11661.	
23 2 AEROMANEUVER	0.	0.1	-932.	10729.	
24 2 MPS POST AERO CORRECT	251.	0.1	-196.	10533.	
25 2 ACS COAST	10.	0.8	-19.	10514.	
26 2 MPS BURN	420.	0.1	-305.	10209.	
27 2 ACS COAST	10.	0.8	-19.	10191.	
28 2 ACS REND/DOCK	40.	1.0	-63.	10128.	
STAGE 3					
29 3 ACS COAST	20.	6.6	-467.	152777.	
30 3 MPS PERIGEE BURN 3 •	3376.	0.2	-31177.	121600.	
31 3 ACS COAST	10.	60.0	-483.	121117.	
32 3 MPS MIDCOURSE CORRECTION	160.	0.1	-1265.	119852.	
33 3 ACS COAST	10.	60.0	-481.	119371.	
34 3 MPS BURN	2536.	0.1	-17988.	101383.	
35 3 ACS REND/DOCK	40.	0.0	-571.	100811.	
36 3 DROP PAYLOAD	0.	0.0	-65000.	35811.	
37 3 DOCKED AT LUNAR STATION	0.	384.0	-1421.	34391.	
38 3 ACS SEPARATION	10.	0.0	-49.	34342.	
39 3 MPS BURN	2536.	0.1	-5190.	29152.	
40 3 ACS COAST	10.	60.0	-353.	28799.	
41 3 MPS MIDCOURSE CORRECTION	160.	0.1	-320.	28480.	
42 3 ACS COAST	10.	60.0	-352.	28128.	
43 3 MPS BURN	50.	0.1	-115.	28013.	
44 3 AEROMANEUVER	0.	0.1	-2156.	25857.	
45 3 MPS POST AERO CORRECT	251.	0.1	-439.	25418.	
46 3 ACS COAST	10.	0.8	-40.	25378.	
47 3 MPS BURN	420.	0.1	-701.	24677.	
48 3 ACS COAST	10.	0.8	-39.	24638.	
49 3 ACS REND/DOCK	40.	1.0	-144.	24494.	
50 3 DROP LEO PAYLOAD	0.	0.0	-15000.	9494.	

• STAGE 1 GRAVITY/STEERING LOSS (F/S) = 567.
• STAGE 2 GRAVITY/STEERING LOSS (F/S) = 314.
• STAGE 3 GRAVITY/STEERING LOSS (F/S) = 170.

PROPELLANT SUMMARY

STAGE 1			
	MPS USABLE = 66166.	ACS USABLE = 1042.	EPS USABLE = 11.
	NOMINAL = 64863.	NOMINAL = 948.	NOMINAL = 9.
	RESERVES = 1297.	RESERVES = 95.	RESERVES = 2.
	BOILOFF = 30.		
	START/STOP = 125.		
STAGE 2			
	MPS USABLE = 45736.	ACS USABLE = 803.	EPS USABLE = 27.
	NOMINAL = 44888.	NOMINAL = 730.	NOMINAL = 22.
	RESERVES = 898.	RESERVES = 73.	RESERVES = 4.
	BOILOFF = 55.		
	START/STOP = 125.		
STAGE 3			
	MPS USABLE = 58135.	ACS USABLE = 1850.	EPS USABLE = 459.
	NOMINAL = 56995.	NOMINAL = 1692.	NOMINAL = 383.
	RESERVES = 1140.	RESERVES = 168.	RESERVES = 77.
	BOILOFF = 2364.		
	START/STOP = 200.		

Table 2.4.6-2 DRM-6 Timeline (GB OTV)

12:10 PM, 1-JUL-85

BASING/MISSION: GROUND BASED LUNAR MANNED
BRAKE: EXPENDABLE BALLUTE, B/W TEMP = 1500, T/D = 1.5
ENGINE: 2 ADVANCED, THRUST = 10000.
PROPULSION: MPS ISP = 483.2, ACS ISP = 220.0
STAGES: 4

WEIGHTS INPUT

STAGE 1
STAGE END = 9238., JETT BALLUTE = 930.

STAGE 2
STAGE END = 9238., JETT BALLUTE = 930.

STAGE 3
STAGE END = 9238., JETT BALLUTE = 930.

STAGE 4
STAGE END = 8874., JETT BALLUTE = 1870.

MISSION PROFILE	DELTA V (F/S)	DELTA T (HOURS)	DELTA W (LBS)	WEIGHT (LBS)	
STAGE 1					DELIVER TO SPACE STATION FOR VEHICLE ASSEMBLY
1 1 MPS BURN FROM 120 NM CIRC	261.	0.1	-932.	53554.	
2 1 ACS COAST	10.	0.5	-80.	53474.	
3 1 MPS BURN TO 270 NM CIRC	259.	0.1	-908.	52566.	
4 1 ACS REND/DOCK	40.	1.0	-301.	52265.	
5 1 DOCKED AT LEO STATION	0.	72.0	-266.	51999.	
STAGE 2					
6 2 MPS BURN FROM 120 NM CIRC	261.	0.1	-953.	54827.	
7 2 ACS COAST	10.	0.5	-82.	54745.	
8 2 MPS BURN TO 270 NM CIRC	259.	0.1	-929.	53816.	
9 2 ACS REND/DOCK	40.	1.0	-308.	53508.	
10 2 DOCKED AT LEO STATION	0.	48.0	-178.	53330.	
STAGE 3					
11 3 MPS BURN FROM 120 NM CIRC	261.	0.1	-872.	50046.	
12 3 ACS COAST	10.	0.8	-75.	49971.	
13 3 MPS BURN TO 270 NM CIRC	259.	0.1	-850.	49121.	
14 3 ACS REND/DOCK	40.	1.0	-282.	48839.	
15 3 DOCKED AT LEO STATION	0.	24.0	-89.	48750.	
STAGE 4					
16 4 MPS BURN FROM 120 NM CIRC	261.	0.1	-1031.	59408.	
17 4 ACS COAST	10.	0.8	-88.	59320.	
18 4 MPS BURN TO 270 NM CIRC	259.	0.1	-1005.	58315.	
19 4 ACS REND/DOCK	40.	1.0	-334.	57981.	
20 4 DOCKED AT LEO STATION	0.	1.0	-4.	57978.	
21 4 PICKUP 80 K	0.	0.0	80000.	137978.	
STAGE 1					MISSION OPERATIONS
22 1234 DOCKED AT LEO STATION	0.	24.0	-463.	291594.	
23 1234 ACS SEPARATION	10.	0.0	-412.	291182.	
24 1234 ACS COAST	10.	0.8	-428.	290754.	
25 1234 MPS PERIGEE BURN 1 *	2131.	0.2	-39983.	250772.	DROP PAYLOAD
26 1 ACS STAGING BURN	10.	0.0	-16.	11088.	
27 1 ACS COAST	10.	1.1	-21.	11066.	
28 1 MPS DEORBIT BURN	340.	0.0	-264.	10803.	
29 1 ACS COAST	10.	1.1	-21.	10782.	
30 1 MPS BURN	50.	0.1	-60.	10722.	
31 1 AEROMANEUVER	0.	0.1	-930.	9792.	
32 1 MPS POST AERO CORRECT	251.	0.1	-181.	9611.	
33 1 ACS COAST	10.	0.8	-18.	9593.	
34 1 MPS BURN	420.	0.	-280.	9313.	
35 1 ACS COAST	10.	0.5	-17.	9296.	
36 1 ACS REND/DOCK	40.	1.0	-58.	9238.	
STAGE 2					
37 234 ACS COAST	20.	2.2	-710.	238958.	
38 234 MPS PERIGEE BURN 2 *	2733.	0.2	-41461.	197497.	DROP PAYLOAD
39 2 ACS STAGING BURN	10.	0.0	-16.	11039.	
40 2 ACS COAST	10.	1.9	-25.	11013.	
41 2 MPS BURN	259.	0.0	-207.	10807.	
42 2 ACS COAST	10.	1.9	-25.	10782.	
43 2 MPS BURN	50.	0.1	-60.	10722.	
44 2 AEROMANEUVER	0.	0.1	-930.	9792.	
45 2 MPS POST AERO CORRECT	251.	0.1	-181.	9611.	
46 2 ACS COAST	10.	0.8	-18.	9593.	
47 2 MPS BURN	420.	0.1	-280.	9313.	
48 2 ACS COAST	10.	0.8	-17.	9296.	
49 2 ACS REND/DOCK	40.	1.0	-58.	9238.	
STAGE 3					
50 34 ACS COAST	20.	3.5	-565.	185878.	
51 34 MPS PERIGEE BURN 3 *	3233.	0.2	-37055.	148823.	DROP PAYLOAD
52 3 ACS STAGING BURN	10.	0.0	-16.	10993.	
53 3 ACS COAST	10.	4.8	-40.	10952.	
54 3 MPS BURN	151.	0.0	-131.	10822.	
55 3 ACS COAST	10.	4.8	-40.	10782.	
56 3 MPS BURN	50.	0.1	-60.	10722.	
57 3 AEROMANEUVER	0.	0.1	-930.	9792.	
58 3 MPS POST AERO CORRECT	251.	0.1	-181.	9611.	
59 3 ACS COAST	10.	0.5	-18.	9593.	
60 3 MPS BURN	420.	0.1	-280.	9313.	
61 3 ACS COAST	10.	0.5	-17.	9296.	
62 3 ACS REND/DOCK	40.	1.0	-58.	9238.	
STAGE 4					
63 4 ACS COAST	20.	9.7	-439.	137375.	
64 4 MPS PERIGEE BURN 4 *	2033.	0.2	-17118.	120257.	
65 4 ACS COAST	10.	60.0	-481.	119775.	
66 4 MPS MIDCOURSE CORRECTION	160.	0.1	-1251.	118524.	
67 4 ACS COAST	10.	60.0	-479.	118045.	
68 4 MPS BURN	2536.	0.1	-17789.	100257.	
69 4 ACS REND/DOCK	40.	1.0	-570.	99686.	DROP PAYLOAD
70 4 DROP PAYLOAD	0.	0.0	-65000.	34686.	
71 4 DOCKED AT LUNAR STATION	0.	384.0	-1421.	33266.	
72 4 ACS SEPARATION	10.	0.0	-47.	33219.	
73 4 MPS BURN	2536.	0.1	-5021.	28198.	
74 4 ACS COAST	10.	60.0	-351.	27846.	
75 4 MPS MIDCOURSE CORRECTION	160.	0.1	-310.	27536.	
76 4 ACS COAST	10.	60.0	-380.	27156.	
77 4 MPS BURN	50.	0.1	-82.	27074.	
78 4 AEROMANEUVER	0.	0.1	-1870.	25204.	
79 4 MPS POST AERO CORRECT	251.	0.1	-428.	24775.	
80 4 ACS COAST	10.	0.8	-39.	24736.	
81 4 MPS BURN	420.	0.1	-684.	24053.	
82 4 ACS COAST	10.	0.8	-38.	24014.	
83 4 ACS REND/DOCK	40.	1.0	-140.	23874.	
84 4 DROP LEO PAYLOAD	0.	0.0	-15000.	8874.	

* STAGE 1 GRAVITY/STEERING LOSS (F/S) = 167.
* STAGE 2 GRAVITY/STEERING LOSS (F/S) = 223.

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3.0 SYSTEM REQUIREMENTS

This section describes the output of our system requirements task. The task can be divided in two parts: (1) definition of OTV flight profile elements and (2) derivation of system design requirements. This includes derivation of performance requirements, definition of services to be provided to the payload by the OTV, and derivation of kit requirements for missions that cannot or should not be accomplished by the standard OTV configuration.

3.1 FLIGHT PROFILE

This section describes the major OTV mission elements to be used in deriving overall system requirements. Examination of the DRM's showed the flight operations of each OTV mission to be composed of five different flight segment types: 1) pre-flight and post-flight operations, 2) separation and rendezvous maneuvers, 3) orbit transfer/coast, 4) payload delivery and operations, and 5) aeromaneuver. Many of these operations are common to all DRM's, while others are more mission-specific. The operations identified above are also discussed elsewhere in this report, specifically in Book 4 section 3.0. The summary discussion below is intended to put each flight operation in perspective with respect to the overall mission. Specific flight operation sequences are given in section 2.4 Design Reference Missions. Figure 3.1-1 shows a typical mission profile.

3.1.1 PRE-FLIGHT AND POST-FLIGHT OPERATIONS

The OTV pre-flight and post-flight operations are summarized here for both ground- and space-based vehicles. Pre-flight operations for the GB OTV include ground operations and the ascent to LEO in the shuttle orbiter. Pre-flight and post-flight operations for the SB OTV are performed at the space station.

GB OTV. Following checkout, the GB OTV, its airborne support equipment, and its payload are mated and undergo integrated tests. The integrated assembly is then transferred to the launch pad and installed in the Shuttle Orbiter where propellant loading of the launch vehicle and the OTV are accomplished. Following launch and circularization to a 120 nautical mile orbit with an inclination of 28.5^{o}, the Orbiter payload doors are opened and the OTV undergoes a predeployment checkout. The GB OTV is then deployed.

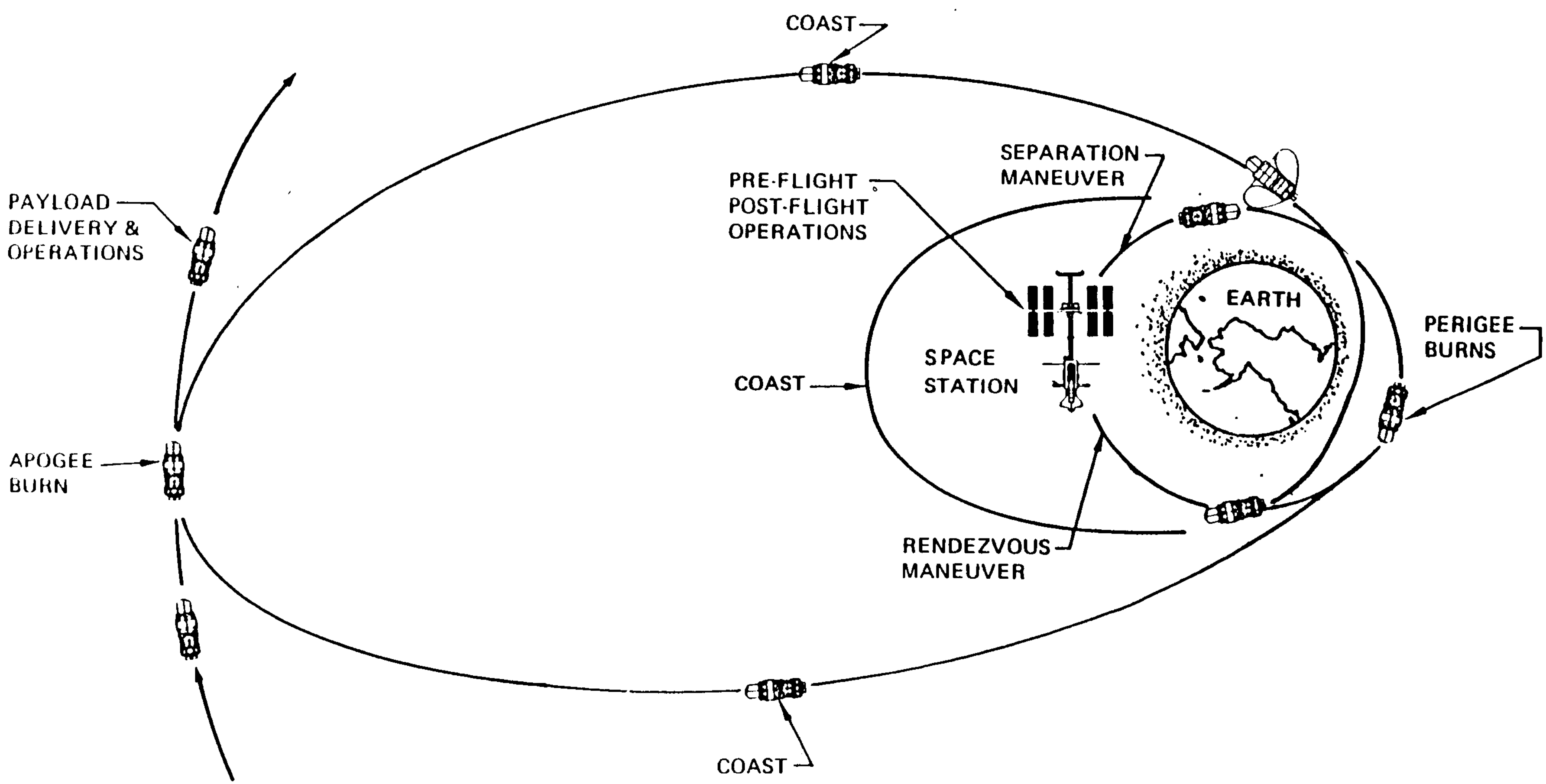


Figure 3.1-1 OTV Mission Profile

OTV-1022

Post-flight operations begin when the OTV is returned to the Orbiter payload bay using the remote manipulator system, latched into the airborne support equipment structural adapter, stowed into the payload bay, and returned to the launch site for subsequent refurbishment for a later flight.

During the period that the OTV is within the Orbiter payload bay, command and control is accomplished by GSE and Orbiter systems prior to launch and through Orbiter systems after launch. When deployed outside the Orbiter, command and control is accomplished by a STDN/TDRS compatible RF link. The OTV is capable of autonomous mission operation and is capable, by addition of a kit, of providing a secure communication link if required.

SB OTV. The SB OTV is mated with its payload at the Space Station (270 nmi, 28.5° orbit). Integrated tests, propellant loading, and pre-deployment checkouts are also performed at the Space Station. The SB OTV is not ready for deployment until the Space Station reaches the proper ascending node alignment (to reach the proper GEO longitude). This differs from the GB OTV where the phasing operation is done after deployment from the Orbiter.

The SB OTV post-flight operations begin after OTV capture by the OMV in LEO. The OMV returns the OTV to the Space Station where it is secured and separated from the OMV. This is followed by post-flight checkout and refurbishment.

3.1.2 SEPARATION AND RENDEZVOUS MANEUVERS

Separation and rendezvous maneuvers occur at the beginning and end of each OTV mission from/to a launch platform (space station or orbiter, depending on whether the OTV is space- or ground-based). The separation maneuver involves the actual process of separating from the launch platform and the coast period prior to main engine ignition. The rendezvous maneuver involves the period from the aeromaneuver to actual retrieval by the launch platform. The rendezvous/separation maneuvers associated with manned GEO operations (i.e., MGSS) have not been investigated.

Launch and retrieval are both conducted via an RMS grapple interface with STS/RMS or OMV/RMS. After separation the OTV coasts and positions itself for its first transfer orbit injection burn. During this period the OTV is in communication with its launch platform. In the case of a GB OTV this coast period may include a number of phasing orbits.

The rendezvous coast period includes a number of MPS burns required to correct errors in altitude, velocity, and inclination. During this period it is in communication with its launch platform. Its guidance system also requires GPS position updates.

Capture by the OMV or orbiter is facilitated by radar corner reflectors. Active rendezvous by the OTV would require the addition of a rendezvous radar system (this may be required for MGSS rendezvous).

3.1.3 ORBIT TRANSFER/COAST

Most of the OTV mission time is spent either in a transfer orbit (e.g., LEO to GEO) or in a destination orbit (e.g., GEO). The transfer orbit is characterized by one or more MPS burns, each followed by a coast period, terminating with either an MPS burn (e.g., upleg, GEO phasing) or an aeromaneuver (downleg). Requirements for the transfer orbit include position and orientation of the OTV prior to MPS burns, the MPS burns, maintenance of orbital parameters during coast including RCS mid-course correction, and maintenance of vehicle attitude during coast (e.g., payload thermal roll).

The typical upleg transfer orbit has two perigee burns, a midcourse correction, and an apogee circularization/plane change burn. The typical GEO phasing orbit has a small MPS phasing burn, a midcourse correction, and a small MPS circularization burn. The typical downleg transfer orbit has a de-orbit/plane change burn, and a midcourse correction, leading up to the aeromaneuver. The exception to this is the planetary mission (DRM-3), where the payload is deployed (on an escape trajectory) on the upleg and the OTV is immediately decelerated to allow return to Earth.

3.1.4 PAYLOAD DELIVERY AND OPERATIONS

When the OTV reaches its target orbit, it can either deploy its payload or initiate a mission operations sequence, such as rendezvous and dock with MGSS. The payload deployment is preceded by an ACS positioning maneuver. The payload is then activated by the OTV (timing discretes are one of the few OTV payload services) and released. The OTV then backs off and begins a coast period while waiting for the proper nodal alignment for return to LEO.

The manned missions have different operational sequences. With GEO servicing (DRM-4), the OTV rendezvous and docks with the MGSS where it remains active but under MGSS control for the duration of the GEO operations. With the manned lunar sortie the operational sequence is similar to the Apollo mission profile. After circularization in lunar orbit part of the crew transfers to an expendable lunar excursion module (LEM) for descent to the lunar surface. The OTV with its crew module functions as the command module until the LEM returns from the surface and the entire crew returns to Earth using the OTV.

Missions in which the OTV picks up a payload in the target orbit for return to LEO were not identified in the mission model and so were not analyzed.

3.1.5 AEROMANEUVER

An aeromaneuver is performed on the return leg of each OTV mission. The aerobrake increases the OTV drag coefficient and provides thermal isolation so the OTV can use atmospheric drag to dissipate excess kinetic energy rather than slow the vehicle all-propulsively. The aeromaneuver is preceded by an alignment burn (prior to atmospheric entry) and followed by a correction burn to compensate for errors and atmosphere variations. Both of these burns require GPS navigation inputs. The OTV must navigate completely autonomously during the aeromaneuver itself because communications are interrupted during the atmospheric pass.

3.2 SYSTEM DESIGN REQUIREMENTS

The key design requirements for the OTV system are provided. The requirements shown are those that primarily affect the flight system.

3.2.1 System Level Requirements

The requirements that affect the overall configuration and operations are presented in table 3.2.1-1.

3.2.2 Subsystem Requirements

3.2.2.1 Structural Requirements

The structural design criteria/guidelines are shown in table 3.2.2-1 and the meteoroid/debris environment in figure 3.2.2-1.

3.2.2.2 Main Propulsion

The top level requirements are as follows:

a. Provide thrust for delta-velocity maneuvers required for geosynchronous and other high energy maneuvers.
b. Be reuseable for at least 10 missions to minimize recurring costs.
c. Satisfy man-rating requirements.
d. Be capable of operating in either a ground based or space based mode.

TABLE 3.2.1-1 OTV SYSTEM LEVEL REQUIREMENTS

- General

  - Reusability--All vehicles to be designed to be retrieved and refurbished

    - Airframe - 40 mission service life
    - Tankage - 40 mission service life
    - Avionics - 40 mission service life
    - Aeroassist - 1 mission life for ballute

      5 mission life for lifting brake

      20 mission life for shaped brake
    - Main Engine (ASE) - 10 hours, 20 flights
    - On-Orbit Storage Tanks - 5 year service life
    - Airborne Support Equipment - 100 flights with refurbishment

  - Satisfy Safety Requirements per NHB 1700.7

    - Shuttle/Space Station
    - OTV Mission - No single credible failure shall preclude the safe return of the crew

  - Any hardware jettisoned during a mission shall be disposed of through controlled deorbit or other acceptable non- interference mode

  - OTV System shall be NASA STDN and TDRS compatible (communications and tracking)

  - The OTV design shall include the following flight performance reserves:

    - Main propulsion - 2% on each delta-V maneuver
    - Reaction control system - 10% of mission nominal RCS propellant
    - Electrical power system - 20% of mission nominal reactants

  - Mission Times - Use 12 hours at LEO for phasing

    - DRM-1 45 hours
    - DRM-2 56 hours
    - DRM-3 43 hours

TABLE 3.2.1-1
OTV SYSTEM LEVEL REQUIREMENTS
(CONTINUED)

- DRM-4 — 396 hours
- DRM-5 — 417 hours

- Pre-Launch
  - Ground services (electrical, fluid, and gases) will be through orbiter service panels
- Launch
  - The OTV and its payload will be launched to orbit by the STS, either in the Orbiter cargo bay or in the aft cargo carrier (ACC) from either WTR or ETR
  - The sum of the masses of the OTV and its consumables, the airborne support equipment and its consumables, orbiter- furnished airborne support equipment, and payload shall not exceed the weight determined by the following:

    Launch wt = 87,960 - 114 (altitude, in nm)
  - The OTV system shall provide for a structural adaptor and a deployment/release mechanism
  - Satisfy the static and dynamic loads, thermal, contamination, physical envelope, CG, and other requirements of payload accommodations handbook, Vol XIV of JSC document 07700
  - The OTV system shall provide for the dumping of propellants through the orbiter service panels in the event of an abort
- Mission - Significant Payloads
  - 20,000 lb delivery to GEO limited to 0.1 g max. acceleration
  - 10,000 lb multiple-manifest payload to GEO
  - 7500 lb GEO manned sortie with 7500 lb return
- Recovery
  - (Space-Based) retrieved by OMV from parking orbit - OTV to remain passive during docking and reberthing at space station
  - (Ground Based) retrieved by shuttle RMS from parking orbit
    - OTV to remain passive during docking and reberthing
    - Reconnect umbilicals for purge and status monitoring prior to reentry
- Weight Contingency
  - The weight contingency for the OTV flight systems shall be 15% for new hardware and 5% for existing hardware

TABLE 3.2.1-1
OTV SYSTEM LEVEL REQUIREMENTS
(CONTINUED)

- Kits
  - The OTV shall use plug-in kits to meet specialized mission requirements that would adversely affect OTV cost and performance for most other missions

- Payload Services
  - Provide structural attachment points
  - Provide power and data interface
  - Provide capability to transfer at no more than 0.1g
  - Provide a thermally neutral environment

TABLE 3.2 2-1

OTV STRUCTURAL DESIGN CRITERIA/GUIDELINES

- MAJOR STRUCTURE DESIGNED TO WITHSTAND LIFTOFF LOADS
  - N_x = -3.2 G (LIMIT)
  - N_y = $\pm$1.4 G (LIMIT)
  - N_z = $\pm$2.5 G (LIMIT)
- PRIMARY STRUCTURE
  - ULTIMATE LOAD = 1.5 x LIMIT LOAD

	REUSABLE LH_2	REUSABLE LO_2
o TANKAGE		
o LEAK BEFORE RUPTURE	YES	YES
o MINIMUM FACTOR OF SAFETY TO YIELD	1.5	1.5
o DESIGN SERVICE LIFE (MISSIONS)	45	45
o VENT TO REFILL	YES	PARTIAL
o EQUIVALENT FULL DEPTH CYCLES	55	4
o CONTINGENCY CYCLES	5	5
o SCATTER FACTOR	2	2
o DESIGN CYCLES	120	18
o ROOM TEMP PROOF FACTOR	1.63	1.33

- METEOROID/DEBRIS SHIELDING
  - PROVIDE .999 PROBABILITY OF NO TANK WALL IMPACT PER MISSION
  - MINIMUM METALLIC SHEET IS ASSUMED TO BE .016 in FOR BUMPER

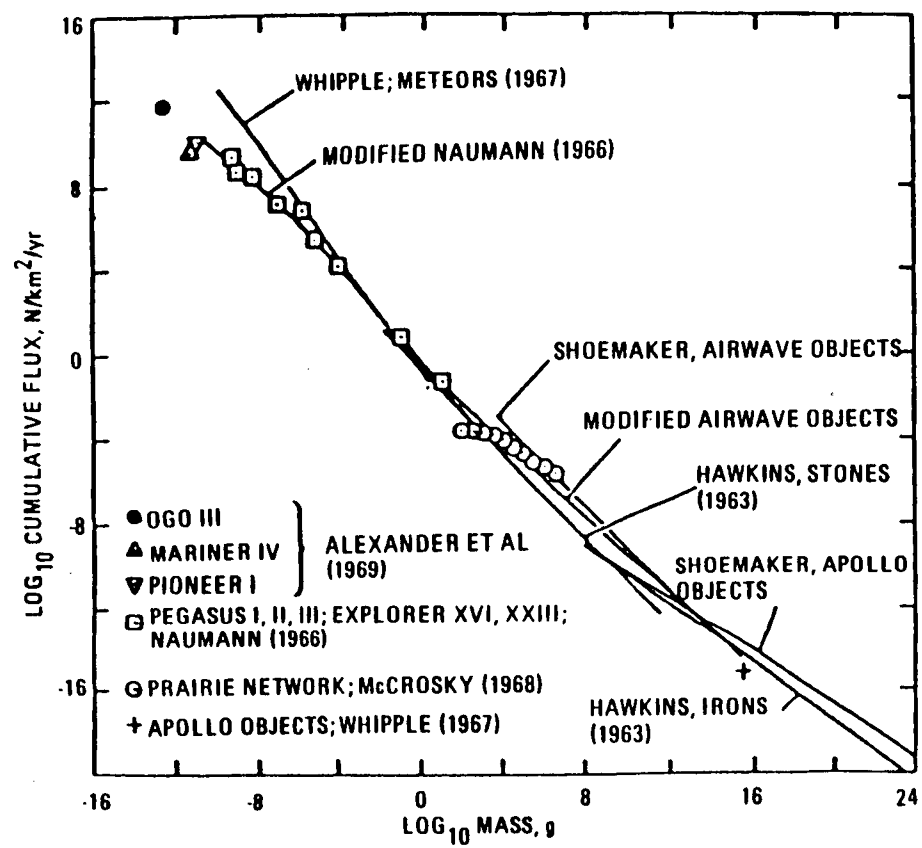
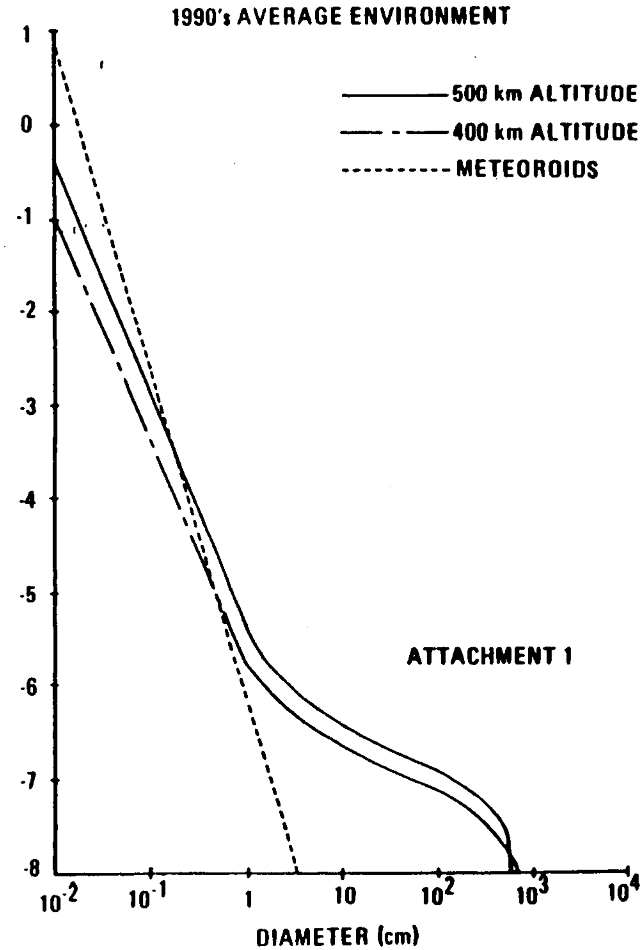


FIGURE 2-13. TERRESTRIAL MASS-INFLUX RATES OF METEOROIDS. N IS THE FLUX OF PARTICLES WITH MASS GREATER THAN m (2-29).

METEOROIDS

NASA TM 82478, "SPACE AND PLANETARY ENVIRONMENT CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT" REV 1982 VOLUME I



DEBRIS

JSC-20001, "ORBITAL DEBRIS ENVIRONMENT FOR SPACE STATION", D. J. KESSLER, 1984.

Figure 3.2.2-1. Meteoroid/Space Debris Environments

OTV-595

e. Be compatible with shuttle launch capability.

3.2.2.3 Reaction Control System

The reaction control system is used to control the vehicle orientation during coasting periods and perform maneuvers which do not warrant use of the main propulsions system. Top level requirements to support the OTV missions and objectives are:

a. Provide thrust for delta-velocity maneuvers of less than 20 ft/s.
b. Be reuseable for at least 20 missions to minimize recurring costs.
c. Satisfy man-rating requirements.
d. Control orientation of the vehicle and provide initial pointing for main propulsion system start.
e. Be capable of operating in either a ground based or space based mode.
f. Be compatible with shuttle launch.
g. Provide six degree of freedom for docking maneuvers.

3.2.2.4 Thermal Protection and Control

The top level requirements are as follows:

a. Provide an aerodynamic surface capable of operating while subjected to the aerothermal environments associated with the aeropass maneuver.
b. Protect the primary structure from effects of the aerothermal environment.
c. Provide a means of dissipating heat generated by the avionics unit, and also of protecting the avionics components from the aerothermal environment during the aeropass maneuver.
d. Reusability or easy replacement.
e. Capability of being assembled or deployed in orbit.
f. Light weight.

3.2.2.5 Guidance and Navigation

The top level requirements for the guidance and navigation subsystem in contributing to transfer to the payload orbit and return to LEO are:

a. Provide vehicle attitude determination.
b. Provide vehicle position data.
c. Provide vehicle velocity status.

3.2.2.6 Communication and Data Handling

The top level requirements for the communications and data handling subsystem are:

a. Communications.

1. Provide telemetry, tracking, and communications between the vehicle and other support elements. These elements include the Orbiter (hardline through the ASE and RF), the Space Station (hardline and RF), ground (hardline through Orbiter umbilicals and RF), and TDRS (RF).
2. Provide ranging signal turnaround for both TDRS and GSTDN.
3. Provide components to achieve the cost optimum unmanned configuration with capability to incorporate additional equipment for a dual failure tolerant man-rated configuration.
4. Provide a telemetry, tracking, and command transmission capability compatible with STDN and TDRS when in flight outside the Orbiter.

b. Data Handling.

1. Provide measurement of the status of vehicle subsystems. Acquire the data, condition it as required, format it, and provide it to telemetry and to the software for computation as required.
2. Perform computational tasks for all vehicle subsystems and vehicle GN&C.
3. Provide built-in test capability to isolate failures to LRU.
4. Perform vehicle automatic checkout.
5. Provide redundancy management.
6. Provide components necessary for cost optimum unmanned vehicle and man-rated vehicle.

3.2.2.7 Electrical Power

The top level requirements for the electrical power subsystems are:

a. Provide power to all vehicle subsystems.
b. Provide capability to supply power to vehicle subsystems from the ground or Orbiter when in the launch configuration, from internal sources when deployed, and from the Space Station when attached.
c. Provide redundancy of internal power sources.
d. Control and distribute power to all vehicle subsystems.
e. Provide interconnecting wiring for all vehicle subsystems except for instrumentation wiring and RF cabling.
f. Provide 200 watts of power to a payload when attached.

4.0 REFERENCES

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